THE ONTARIO HIGH SCHOOL

LABORATORY MANUAL

IN PHYSICS

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PREFACE

This Laboratory Manual has been prepared to accompany the Ontario High School Physics.

As will be seen, it contains a large number of exercises. A considerable number are qualitative, being intended to introduce new ideas and impress fundamental principles; but the majority are quantitative, and are intended to lead to methods of accurate measurement of physical quantities of various kinds.

By making the number of exercises large and giving alternative methods for performing some of the experiments, schools whose supply of apparatus is not large will be able to choose a satisfactory course suitable to their equipment.

In many cases the apparatus required is so simple that it can be constructed by the teacher or by the senior students. Nothing can be more interesting or advantageous to the ingenious student than to construct his own apparatus, and wherever possible this should be encouraged; the necessary apparatus, moreover, is of an inexpensive nature and can now be readily obtained in the Province.

Some of the experiments (for instance, those on the microscope and telescope, Exercises 86 to 90) are beyond the work of the Middle School; but, as they are simple and have interesting practical applications, they have been included.

The values of the physical constants, contained in the tables in the Appendix, have been taken from the *Smithsonian Physical Tables* published by the Smithsonian Institution, Washington, D.C. A volume such as this should be in every physical laboratory.

TORONTO, June, 1911.

CONTENTS

Part I—Mensuration, Units, Density

Part II—Mechanics and Properties of Matter

Part III—Mechanics of Fluids

PART I—MENSURATION, UNITS, DENSITY

Exercise 1.—Determine experimentally the value of π (the ratio of the circumference to the diameter of a circle).

APPARATUS:—Accurately-made circular wooden or metal discs from 2 to 8 inches in diameter, large coins, or cylindrical cans; strips of thin paper; fine wire, such as florists use; metre stick.

(a) *Measure the Diameter.* Lay the metre stick on a face of the disc so that the graduated edge lies along a diameter (Fig. 1), and adjust it so that one edge of the disc is exactly at one of the graduations on the stick. Then take the reading at the other edge of the disc, and on subtracting the two readings we get the diameter. If the latter edge comes between two graduation marks, estimate the fraction in tenths, not in halves or thirds as we usually do. It is much simpler to work with decimals.

FIG. 1.—Measuring the diameter of a disc. Lay the graduated edge along a diameter.

Greater accuracy may be obtained by the use of callipers. Figs. 2 and 3 show common forms of this instrument.


FIG. 2.—Callipers.

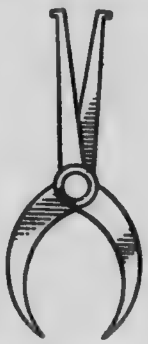
FIG. 3.—Callipers.

The callipers are fitted to the body whose dimensions are to be determined, then removed and the distance between the points measured with a scale.

In some forms of the instrument the scale is attached directly to a bar which carries a sliding jaw as shown in Fig. 9.

Measure five (or more) different diameters. As a final result take the average of all the measurements.

(b) *Measure the Circumference.* Wrap a strip of paper tightly round the edge of the disc, and in the overlapping portion prick a *small* hole with a pin. Then spread the paper out on a table and, laying the metre stick on it, measure the distance between the two holes. This is the length of the circumference. Repeat the process and take the average of all measurements.

Again, wind the fine wire one or more times—according to the size of the disc—about the circumference, and then measure the length of the wire by applying it to the metre stick. Take the mean of five measurements.

Repeat the measurements of diameter and circumference, using different discs, coins or cans.

Record the observations on each disc in a table, such as the following:—

FIRST DISC

Trial.	Diameter.	Circumference.	
		1st Method.	2nd Method.
1	....	....	....
2	....	....	....
3	....	....	....
4	....	....	....
5	....	....	....
Mean	....	....	....
Value of π		....	....

Why is it advisable to use discs of the sizes indicated rather than small ones, say 1 inch in diameter ?

Exercise 2.—Verify the formulas for the area of a circle and of an ellipse.

APPARATUS:—Compasses, squared paper, string and two pins, metre stick.

(*a*) *The Circle.* Draw a circle with radius $1\frac{1}{2}$ or 2 inches on squared paper. The paper is usually divided into mm. or tenths of inches, and hence the area of a small square is 1 sq. mm. or $\frac{1}{100}$ sq. inch. Count the number of complete squares within the circle, and estimate the area included in fractions of squares by counting the number and dividing by two. Then add all together and this will be the area.

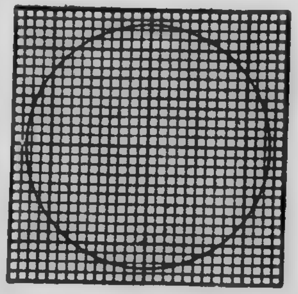

FIG. 4.—Find the area of the circle by counting the full squares and the fractional parts.

Next, measure the radius in mm. or inches (or in lengths of the side of a small square) and calculate the area of the circle from the formula, area $= \pi r^2$ ($\pi = \frac{22}{7}$ or 3.1416). Compare this result with that found by counting the squares.

(*b*) *The Ellipse.* An ellipse may be drawn in the following way. Place the squared paper on a board and put two pins firmly at *A* and *B*. Over these place a loop of string. Pull the string taut by means of a pencil *P*, and then move the pencil about, keeping the string always taut. In this way an ellipse will be drawn having *A* and *B* as foci. Bisect *AB* in *C* and draw *FG* perpendicular to *AB*. *DE* is the major axis $= 2a$ and *FG* is the minor axis $= 2b$. Count the little squares as in the case of the circle and thus obtain the area. Then measure *DE* and *FG* carefully and calculate the area by the formula πab. Compare this with that obtained by counting the squares.

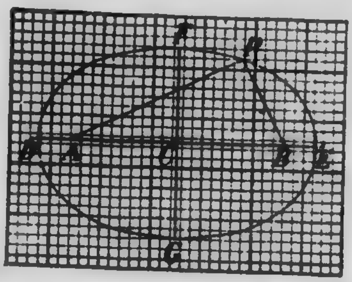

FIG. 5.—Find the area of the ellipse by counting the squares.

Determination of Mass.—Mass is determined by means of the balance (Fig. 6). For description of balance, weights, etc., see TEXT-BOOK, § 11. In using the balance the following rules should be observed:

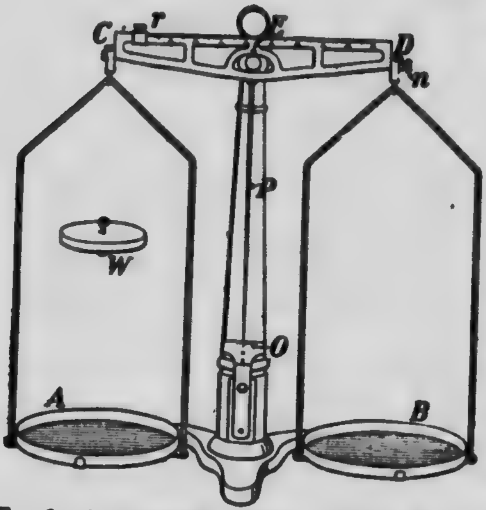

FIG. 6.—A convenient balance. Handle it with great care.

1. Keep the balance dry and free from dust.

2. See that the balance is properly adjusted, so that it will, when unloaded, either rest in equilibrium with the pointer at the zero mark on the scale, or will swing equally on either side of zero.

3. Place the body, whose mass is to be ascertained in the left-hand scale-pan, and place the weights in the right-hand scale-pan. Until some experience in judging the mass of a body has been obtained, try all the weights in order, commencing with the largest and omitting none. When any weight causes the right-hand pan to descend remove it. Never select weights at random.

In the balance shown in the figure any addition under 10 grams is obtained by sliding the rider *r* along the beam. It gives $\frac{1}{10}$ gram directly, and $\frac{1}{10}$ of this may be obtained by estimation.

Before beginning, the balance should be tested. Push the rider *r* over to its zero mark and then if the pans do not balance (as indicated by the pointer *P*) turn the nut *n* until they do.

4. To determine the equilibrium do not wait until the balance comes to rest. When it swings equally on either side of zero, the mass in one pan equals that in the other.

5. Place the largest weight in the centre of the pan, and the others in the order of their denominations.

6. Keep the pans supported when weights are to be added or taken off.

7. Small weights should not be handled with the fingers. Use forceps.

8. Weigh in appropriate vessels substances liable to injure the pans. For counterpoise use shot and paper.

9. Never use the balance in a current of air.

Exercise 3.—Find the value of 1 oz. in grams, 1 kilogram in pounds, 1 quart in c.c. and in litres. (Text-Book, § 11.)

Apparatus:—Balance, with both British and metric weights, quart measure, glass vessel graduated in c.c.

(*a*) Place an ounce weight on the left-hand pan of the balance (Fig. 6) and place metric weights on the right-hand pan to balance it.

(*b*) Next place the kilogram weight on the left pan, and keeping the rider at the zero point, add British weights on the right until they balance the kilogram. Express your result in pounds and decimals.

(*c*) Carefully pour water from the graduated vessel into the quart measure until it is just filled. Then add up the amount poured in. Or, fill the quart measure and empty the water into the glass graduate. Express the quart in c.c. and also in litres. (1 l. = 1000 c.c.)

Exercise 4.—Find the volume of a rectangular solid; also its density. (Text-Book, § 17.)

Apparatus:—Block of wood, metre stick, balance.

Apply the metre stick to each *edge* of the block, thus measuring each dimension of the block four times. Take the average, and by multiplying the three dimensions obtain the volume.

Take measurements in inches as well as in cm. and from the volumes obtained find the number of c.c. in 1 cu. in.

Fig. 7.—A graduate for finding volumes.

Weigh the block and calculate the number of grams in 1 c.c. of it.

Exercise 5.—Find experimentally the volume of a sphere and of a cylinder, and verify the formulas for the volumes of these solids.

APPARATUS :—Sphere (heavier than water) and cylinder (of any convenient size), graduate, beaker, callipers. (The sphere and cylinder should be as large as the graduate and beaker can hold.)

Pour water into the graduate (Fig. 7) and carefully read its height. Water in a glass vessel curves up at the edge; it is the height of the lowest part of the surface which must be observed.

Then carefully drop the sphere in and observe the new level reached by the water. The difference between the two levels is the required volume.

If a graduate large enough to hold the sphere is not at hand a burette and beaker (Fig. 8) may be used.

Place the sphere in the beaker, and allow water to run out of the burette until the sphere is covered. Mark the level on the beaker by a bit of gummed or wet paper. Then remove the sphere, and allow water to run from the burette into the beaker until it reaches the level shown by the gummed paper. From the graduations on the burette one can easily see how much water was required to make up the volume of the sphere. The experiment should be performed several times and results tabulated.

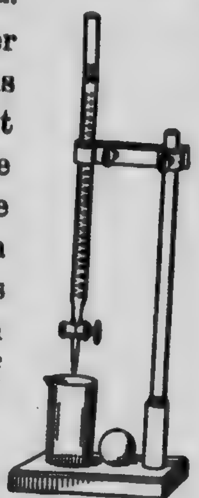

Fig. 8.—Burette and beaker, for finding the volume of the sphere.

The volume of the cylinder may be found in precisely the same way. The volume of an irregular solid, such as a stone or a piece of coal or a potato could be found quite as easily.

In order to find the diameter of the sphere or the cylinder one can use the micrometer gauge (described in the next exercise) or the vernier calliper. A form of the latter is shown in Fig. 9. The scale V on the sliding jaw is the vernier and its object is to measure fractions of a division of the scale S. Usually n divisions on the vernier are equal to $n - 1$ divisions on the scale. Suppose 10 vernier divisions are equal to 9 scale divisions, and that the latter are millimetres. Then 1 division on the vernier is clearly 0.9 mm., and the difference between one scale division and one vernier division is 0.1 mm. In order to explain the action of the vernier consider the enlarged image of the scale and vernier (Fig. 10). The object to be measured is placed between the jaws of the calliper. Suppose the zero on the vernier occupies the position shown in Fig. 10. It is clear that the length AB is equal to 16 mm. + a fraction of a millimetre. To find this fraction, look along the vernier and see where a line on it coincides with a line on the scale. It is seen that division 7 on the vernier coincides with the line c on the scale. Then the fraction to be measured, namely the distance aB, is equal to the difference between the 7 divisions of the scale in the space ac and the seven divisions of the vernier in the space BC. But the difference between one scale division and one vernier division is 0.1 mm. Hence the fractional part is 7×0.1 or 0.7 mm., and the entire space AB is therefore 16.7 mm. or 1.67 cm.

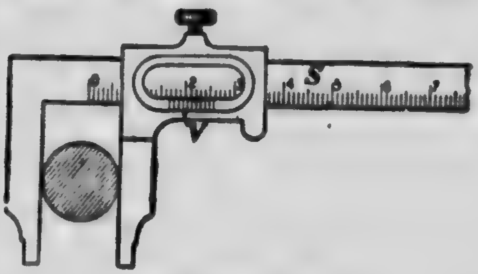

FIG. 9.—Vernier calliper.

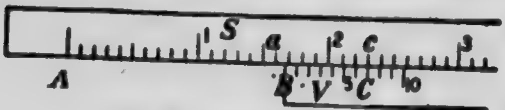

FIG. 10.—Scale and vernier.

For any other vernier the calculation is similar.

Having made several measurements of the diameter of the sphere, take the average. Let it be d. Compare the volume, which is $\frac{1}{6}\pi d^3$, with that found experimentally.

In the case of the cylinder the volume is $\frac{1}{4}\pi d^2 h$ where h is the height of the cylinder.

Exercise 6.—Measure the diameters of several wires and identify the number on the gauge which expresses their diameters. (TEXT-BOOK, § 14.)

APPARATUS:—Samples of wire of different diameters, micrometer gauge.

The micrometer gauge (Fig. 11) is very convenient for measuring the diameters of wires. A is the end of an accurately made screw which works in a nut inside D, and can be moved back and forth by turning the cap C to which it is attached and which slips over D. Upon D is a scale, which counts the number of revolutions of C, while the bevelled end of C is divided into a number of equal parts by which the fractions of a revolution are measured. By turning the cap the end A moves forward until it reaches the stop B, at which time the graduations on D and C should both read zero.

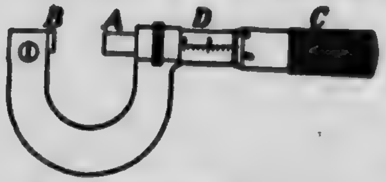

FIG. 11.—Micrometer wire gauge.

In order to measure the diameter of a wire, turn the cap C until the wire just slips between A and B. Then by reading the graduations on D and C we find how far the end A has been drawn back from B, which is the thickness of the wire.

Suppose the pitch of the screw to be $\frac{1}{2}$ mm. Then when C rotates once, the end A moves through $\frac{1}{2}$ mm. Now if on C there are 50 divisions it is evident that when it turns through one division the end A moves through $\frac{1}{50} \times \frac{1}{2} = \frac{1}{100}$ mm. Such an instrument will measure to $\frac{1}{100}$ mm.

Sometimes the pitch of the screw is $\frac{1}{40}$ inch and there are 25 divisions on the head *C*, in which case one division = $\frac{1}{25} \times \frac{1}{40} = \frac{1}{1000}$ inch.

When making a measurement hold the cap *C* lightly and turn the screw until the wire is just grasped between *A* and *B*. The instrument must not be screwed up tight, as that would destroy the accuracy of the screw, and moreover the wire would be somewhat flattened.

Having measured each wire at five different places, take the average. Then compare your results with the sizes given in the following table and see to what number on this gauge the wires correspond:—

BROWN AND SHARPE (AMERICAN) GAUGE

No. of Wire..	1	2	3	4	5	6	7	8	9	10
Diam. in mm.	7.35	6.54	5.83	5.19	4.62	4.12	3.66	3.26	2.91	2.59
No. of Wire..	11	12	13	14	15	16	17	18	19	20
Diam. in mm.	2.30	2.05	1.83	1.63	1.45	1.29	1.15	1.02	.91	.81
No. of Wire..	21	22	23	24	25	26	27	28	29	30
Diam. in mm.	.72	.64	.57	.51	.45	.40	.36	.32	.29	.25

Exercise 7.—Find the pitch of a screw.

APPARATUS:—Several bolts of different diameters, metre stick.

Place the metre stick against the threads of the screw (Fig. 12) and count the number of threads in any length, say 1 cm. or 1 inch. Then the pitch is given by stating the number of threads per cm. or inch.

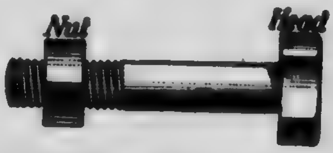

FIG. 12.—A bolt. Find the pitch of the screw.

The measurements may be verified by rotating the nut a definite number of turns and measuring

the increase or decrease of the distance between the head and the nut.

FIG. 13.—Finding the cross-sections of a tube.

Exercise 8.—Find the cross-section and the internal diameter of a glass tube.

APPARATUS:—Glass tube, burette or other measuring glass, bits of paper and rubber bands, metre stick.

Cork one end of the tube and pour in water enough to cover well the cork, marking the level A (Fig. 13) of the water by a bit of paper held in place by a rubber band or simply wet and stuck on. Then run in a measured quantity of water and mark the new level B. By means of the metre stick measure the distance between the two levels A and B.

$$\text{Then area of cross-section} = \frac{\text{Volume}}{\text{Height}}.$$

Repeat several times with different volumes and arrange the results as follows:—

No. of Trial.	Volume Run In.	Height in Tube.	Cross-section.
....	....	....	....
....	....	....	....
....	....	....	....
....	....	....	....
	Average cross-section		....

The experiment may be varied by first placing the paper marks a certain number of centimetres apart and then filling the tube, the amount poured in being read from the graduate.

Having obtained the cross-section, the diameter d may be obtained from the formula, area $= \frac{1}{4}\pi d^2$ Compute the diameter.

The internal diameter of the tube can be determined by direct measurement by using as a gauge a wedge of squared millimetre paper of the form shown in (Fig. 14). Thrust the wedge into the tube, keeping the side *a b* of the paper against the wall of the tube, and read from the squares the diameter.

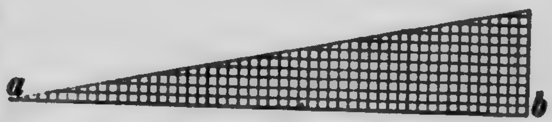

Fig. 14.—Gauge for measuring internal diameter of a tube.

Callipers are used to determine the diameters of large tubes. When two pairs of points are provided (Fig. 3), the one is used in measuring external, and the other internal diameters. When the instrument has but one pair of points, internal diameters are measured by making the limbs overlap as shown in Fig. 2.

Exercise 9.—Find the relation between the force employed to stretch a coil-spring and the amount of the stretch produced: test a spring-balance. (TEXT-BOOK, § 163.)

APPARATUS:—A coil spring, weights, curve paper, spring-balance, graduated in ounces and grams.

A suitable spring may be made by winding spring brass wire (No. 18 or 20) on a round rod about 1 cm. in diameter, the spring thus formed being 8 or 10 cm. long. A simple form of apparatus is shown in Fig. 15. The string attached to the lower end of the spring hangs parallel to and near the edge of a graduated scale *S*. In the string is a knot *A* which serves as an index.

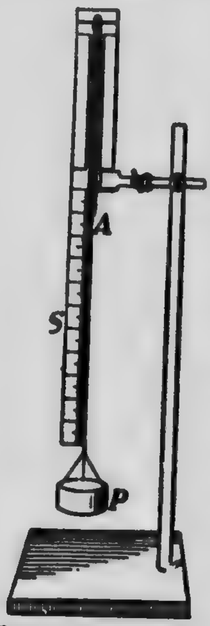

FIG. 15.—Find the relation between the load on the spring and the stretch produced.

First remove the scale-pan *P*, place it on an ordinary balance (see Fig. 6) and add small shot or tacks until it weighs 10 grams. Replace it and observe the position of the index *A*, which is the reading when the spring is stretched by a force of 10 grams. Add 10 grams and read the index again. Continue adding weights and reading the scale for each weight.

Arrange your results in a table giving in the 1st column the stretching force, in the 2nd the reading on the scale, in the 3rd the amount of the stretch, and in the 4th the values obtained on dividing the stretching force by the amount of stretch produced by it.

Next plot your results on a sheet of curve paper (Fig. 16). Draw lines *OX*, *OY* at right angles. These we shall call axes

of reference; distances measured along OX will be known as *abscissae*, those measured perpendicular to OX (*i.e.*, parallel to OY) will be known as *ordinates*. Represent the different stretching forces by lengths along OX and the corresponding amounts of stretch by distances along OY.

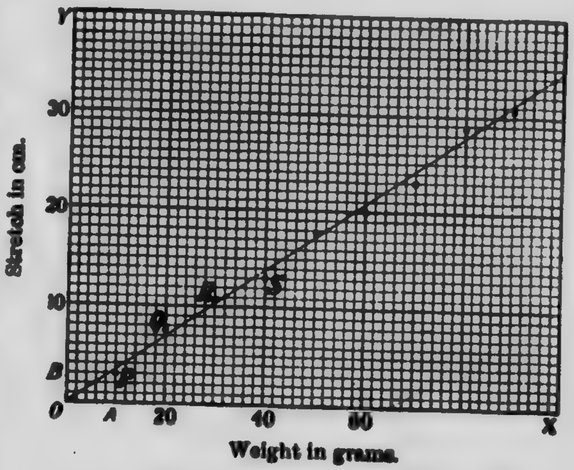

FIG. 16.—Representing results by means of a curve.

Let OA represent 10 grams and OB represent (say) 3.5 cm. (the amount of stretch). Then at A erect a perpendicular $AP = OB$. In this way we obtain a point P. Obtain, in the same way, a point corresponding to each set of readings. Let these points be $P, Q, R, S, \ldots$. Then through these points draw a freehand curve. In this case it is approximately a straight line. This graphical method of representing the results of an experiment is of very great utility.

In order to test the spring-balance hang on its hook the little pan and its load (10 grams in all). Then continually add weights to the pan, noting in each case the reading on the scale of the balance. Enter in two columns the load on the pan and the corresponding reading on the balance, and thus determine what corrections, if any, should be made to the latter. If the balance reads in pounds or ounces the British weights should be used.

Exercise 10.—A study of the lever. (TEXT-BOOK, §§ 50-52, 82-84.)

APPARATUS:—Metre rod, hardwood prism, set of weights, spring-balance.

Lever of Class I. Lay the metre rod on the prism, with the 50 cm. mark exactly over the edge of the prism (Fig. 17). If the stick does not balance add bits of lead to the lighter end until it does. Put blocks under the ends to reduce the vibration.

FIG. 17.—A lever of the first class.

Place a weight P on some graduation, noting its distance from F. This distance is called the arm of the lever, and the product $P \times FP$ is called the moment of P about F. Move the weight W until it just balances P, and note the length FW.

Make 5 or 6 experiments, changing the weights, and tabulate the results as follows:—

P.	Arm of *P.*	Moment of *P.*	*W.*	Arm of *W.*	Moment of *W.*

Lever of Class II. Weigh the rod; let it be w grams. Next find the position of the centre of gravity of the rod by balancing it on the prism. Support it at this point by a weight w attached to a string as shown in Fig. 18. Let it be at C.

Now rest the rod on a prism at a point 2 cms. from one end and attach a spring-balance 2 cm. from the other end. Place a weight W on the rod, noting its distance from the fulcrum F, and observe the reading P of the spring-balance. Make at least 5 different experiments, varying W and FW, and arrange the results as in the table:—

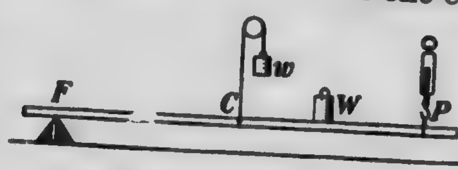

FIG. 18.—A lever of the second class.

Moment of W $W \times CF$.	W.	Arm of W FW.	Moment of W $W \times FW$.	P.	Arm of P FP.	Moment of P $P \times FP$.

Lever of Class III. For a lever of the third class support the metre rod at its centre of gravity as in the last exercise, and push it through a wire loop fastened to the table and transpose the positions of P and W (Fig. 19).

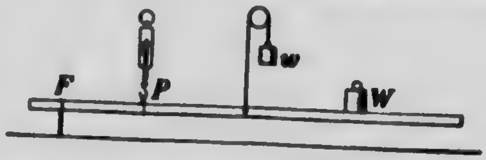

FIG. 19.—A lever of the third class.

Arrange the results in a table as in the other cases.

Exercise 11.—Law of the lever when the forces are not perpendicular to its length. (TEXT-BOOK, §§ 51, 52.)

APPARATUS:—Metre rod with holes drilled through it, pulleys and weights (or spring-balances).

Drive a pin (a wire nail with its head removed) in a board on the table; over this lay a sheet of paper; on the pin thread a large bead and also the metre rod, so that the pin passes through the centre hole. The bead will keep the rod from the table and will allow it to turn freely in a horizontal plane.

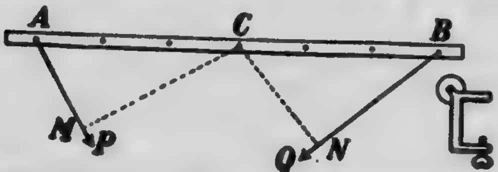

FIG. 20.—A lever with forces not perpendicular to its length.

Attach strings to any points A, B (Fig. 20) of the rod, and let these pass over pulleys at the edge of the table, with weights P and Q on the ends of the strings.

Mark on the paper the directions AM, BN of the strings and draw CM, CN, the perpendiculars from C upon these lines. Carefully measure the lengths of CM, CN. The moment of P about C is $P \times CM$; that of Q is $Q \times CN$.

Take different values of P and Q, and tabulate results as before.

In place of weights over pulleys spring-balances may be used.

Exercise 12.—Find the centre of gravity and the weight of a graduated rod. (TEXT-BOOK, §§ 72-74.)

APPARATUS :—Graduated rod and a weight.

Lay the rod on the edge of the prism (Fig. 21) and observe the graduation C where it balances. The centre of gravity is at this place.

FIG. 21.—Finding the centre of gravity of a rod and its weight.

Next rest the rod on the prism at another place in its length, and move a weight W along it until it balances again. If w is the weight of the rod, we have

$$w \times CF = W \times WF$$

from which w can be found.

Vary the weight W and the distance WF and obtain at least 5 results, which should be tabulated.

Exercise 13.—Find the resultant of parallel forces. (TEXT-BOOK, § 51.)

APPARATUS :—Metre rod, spring-balances, heavy weight.

Support the rod at its centre of gravity as in Exercise 10, and attach spring-balances at A and B, say 10 cm. from each end of the rod (Fig. 22). Hang a heavy weight W at any place. Take the readings P_1, P_2 on the balances and the distances l_1, l_2 of the weight from B and P_1.

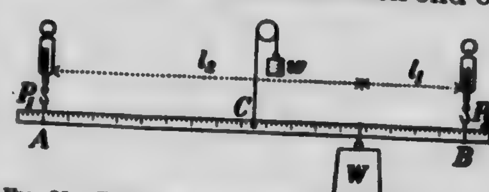

FIG. 22.—Finding the resultant of parallel forces.

Place W at various positions on the rod and enter results in a table as follows :—

P_1.	P_2.	$P_1 + P_2$.	W.	$P_1 \times l_2$.	$P_2 \times l_1$.

Also compare $P_2 \times (l_1 + l_2)$ with $W \times l_2$, *i.e.*, take moments about A; and $P_1 \times (l_1 + l_2)$ with $W \times l_1$, *i.e.*, take moments about B.

Exercise 14.—Find the resultant of two forces acting at a point (Parallelogram of Forces). (TEXT-BOOK, § 55.)

APPARATUS:—Spring-balances, small ring, cord.

Fasten three cords (fish-line) to a small ring, and hook spring-balances on the other ends of the cords (Fig. 23). By means of pins in the top of the table, over which the rings of the balances may be placed, or in any other convenient way, exert force on the balances so that the cords are under considerable tension. The balances should move free of the table top.

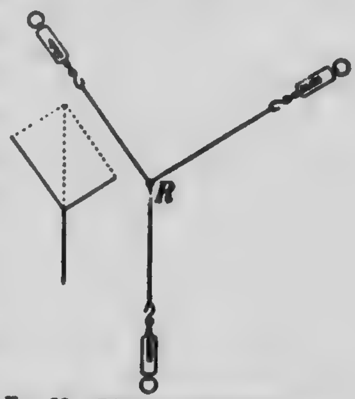

FIG. 23.—Diagram illustrating the parallelogram of forces.

Pin a sheet of paper under the strings and mark a dot precisely at R, the centre of the ring; also make dots exactly under each string and as far from R as possible.

Read each balance. Then loosen them, and when they are lying on the table observe if the index returns to zero. If it does not a correction to the reading on the balance must be made.

With great care draw lines from R through the points under the cords, and on these lines take distances proportional to the tensions of the corresponding strings. Thus if the tensions be 1000, 1500, 2000 grams take lengths 10, 15, 20 cm. or 4, 6, 8 inches.

Using any two of these lines as adjacent sides, complete a parallelogram, taking care to have the opposite sides accurately parallel. Draw the diagonal between these sides and carefully measure its length. Compare it as to length and direction with the third line.

Apply your results to verify the triangle of forces.

Exercise 15.—A study of the action of pulleys. (TEXT-BOOK, §§ 55-87.)

APPARATUS :—Systems of pulleys as in Figs. 24, 25, 26. The pulleys should work with very little friction. Aluminium pulleys are recommended.

Place a weight W on one pan (Fig. 24), and on the other pan add weights P until W just begins to move upward. If there were no friction P and W would be equal. The friction $= P - W$.

FIG. 24.—Find the relation between P and W.

Take 8 or 10 different values of W and determine the P in each case which will just cause W to rise. Arrange the results in a table with headings P, W, $P - W$. Also draw a curve, having the values of P for ordinates and the corresponding values of $P - W$ for abscissas.

What do you conclude as to the ratio between P and $P - W$?

Make similar experiments with the arrangements shown in Figs. 25, 26. In these cases find the ratio between the distances moved through by P and W; also find, for different values of P and W, the value of the ratio $W/P =$ efficiency.

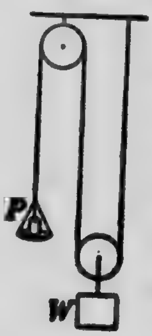

FIG. 25.

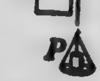

FIG. 26.

Exercise 16.—The principle of work as illustrated in the inclined plane. (TEXT-BOOK, §§ 63-65, 92.)

APPARATUS :—As in Fig. 27.

Set the inclined plane at an angle of 45°. The carriage W and the pulley should move with very little friction. Unless this is the case the experiment will not be satisfactory. Place a weight on W, and then add to P until W just moves up the plane. This can be done by attaching a pail to the string and using sand, water or shot to increase the weight. Let P_1 be the weight in this case. Then lighten P until W just moves down the

plane; let P_2 be the weight now. Take $\frac{1}{2}(P_1 + P_2) = P$ as the weight required to balance W if there were no friction.

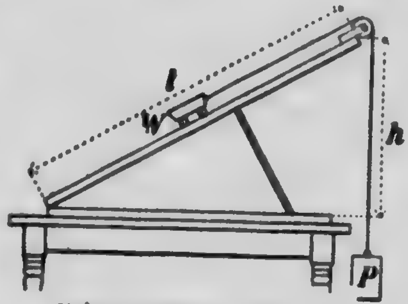

FIG. 27.—Show that $Pl = Wh$.

It is evident that when W passes from one end of the plane to the other it rises through a distance h, the height of the plane, and hence the work done is Wh, while P passes through a distance l, the length of the plane, and so does work Pl. Hence $Pl = Wh$, or $P = W\frac{h}{l}$.

Measure the distances h and l with a metre rod.

Use different values of W and different inclinations of the plane, and tabulate the results thus:—

P_1.	P_2.	$P = \frac{1}{2}(P_1+P_2)$.	h.	l.	Pl.	Wh.	Pl/Wh.

Exercise 17.—A study of the pendulum.

APPARATUS:—Pendulum consisting of a metal sphere suspended by a fine thread from a clamp as in Fig. 28, (or in any other convenient way,) metronome.

Have the metronome beating seconds. The length of the pendulum is the distance from the lower face of the block to the centre of the bob. The motion of the pendulum from its extreme position on either side back to that position again (*i.e.*, a "double-swing,") is called an *oscillation*, and the time taken to make an oscillation is called its *period*. The *amplitude* of the oscillation is the distance from its middle or lowest point to its extreme position.

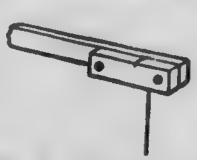
FIG. 28.—One way to suspend a pendulum.

First, test whether a difference in the amplitude of the oscillation produces a change in the period. Use a pendulum 150 cm. long, or even longer, and have as heavy a bob as possible. Count the number of oscillations made in one minute and deduce the period. To determine the time with greater accuracy, a stop-watch may be used if available. Start with various amplitudes, such as 10, 20, 40, 60, 100 cm., and tabulate the results as follows:—

Trial.	No. of Oscillations.	Time.	Period.	Amplitude.	
				At Start.	At End.
1	....	....	....	....	....
2	....	....	....	....	....
3	....	....	....	....	....

What is the effect of a large amplitude?

Second, find the relation between the length of the pendulum and its period. Take pendulums with lengths 150, 120, 100, 80, 60, 25, 10 cm. and find the period for each. For the shorter ones find the number of oscillations in 1 minute or 2 minutes. Arrange the results in a table as below:—

Trial.	Length of Pendulum l.	Period T.	$\frac{l}{T^2}$.
1	....	....	....
2	....	....	....
3	....	....	....

Now plot two curves. In one have length of pendulum as ordinate and period as abscissa. In the other use length of pendulum as ordinate and square of period as abscissa.

Deduce from your curves the length of a pendulum whose period is 1 sec., 2 sec.

State the laws of the pendulum.

It can be shown that if g = acceleration due to gravity, l = length of pendulum and T = its period, then $g = 4\pi^2 \dfrac{l}{T^2}$. From the last column in the table above deduce the values of g.

If a metronome is not at hand the time can be obtained from a watch. Let one student observe the second hand of the watch and call time while the other observes the pendulum.

Exercise 18.—A study of motion with uniform acceleration. (TEXT-BOOK, §§ 26-28.)

APPARATUS:—That shown in Fig. 29. It consists of a board 5 or 6 ft. long with an accurately made cylindrical groove (radius = 4 in.).

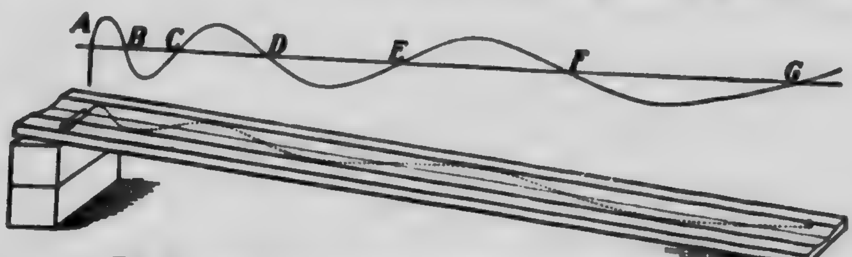

FIG. 29.—Apparatus for studying uniformly accelerated motion.

The surface should be painted black and polished smooth. Near one end a metal strip at right angles to the length of the board projects out to the middle of the groove. A steel or brass sphere, 1 to $1\frac{1}{2}$ inches in diameter is required.

First lay the board on the floor or on a table, and let the sphere oscillate across the groove. Count the time for a large number of oscillations, and deduce the period of a single one.

Now scatter lycopodium powder on the groove. This can be done through 4 or 5 thicknesses of muslin. Then raise one end of the board about 8 in., and placing the sphere at one side of the groove and next the metal strip, let it go. It oscillates across the groove and at the same time runs down the board, and the metal strip causes it to start down with no velocity.

Blow off the powder, and there will be left a curve like that in the figure. With a metre rod measure the distances AB,

AC, AD, ... along the middle of the groove. Call these s_1, s_2, s_3, s_4, ... If 2τ is the time of an oscillation the times required to travel these distances are τ, 2τ, 3τ, 4τ, ... Find the ratios

$$\frac{s_1}{\tau^2}, \frac{s_2}{(2\tau)^2}, \frac{s_3}{(3\tau)^2}, \frac{s_4}{(4\tau)^2} \cdots$$

Each of these should be equal to $\frac{1}{2}a$, where a = acceleration.

Try the experiment with at least 2 inclinations.

Draw a curve having space travelled as ordinates and the squares of the times required to travel the corresponding spaces as abscissas.

Exercise 19.—Find the coefficient of friction between pine and pine. (TEXT-BOOK, §§ 77-79.)

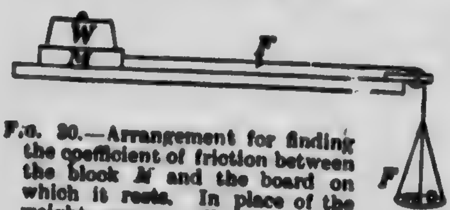

FIG. 30.—Arrangement for finding the coefficient of friction between the block M and the board on which it rests. In place of the weight over a pulley a spring-balance may be used.

APPARATUS:—As shown in Fig. 30. The apparatus used in Exercise 16 may be employed for this purpose.

Weigh the block M; let it be w. Rub it to and fro vigorously on the supporting board. Then place a weight W on it. Place a small weight in the scale-pan and add others in succession until uniform motion takes place. Gently tap the board each time a weight is added to the scale-pan. Note the total force F producing the motion. Then

$$\text{Coefficient of friction} = \frac{F}{W + w}.$$

Try various weights and make many experiments. Having obtained a value of the coefficient for each weight tried, draw a curve using the total weight $W + w$ as ordinates, and F the force exerted as abscissas.

Arrange the results in a table, having as headings of the columns $W + w$, F and $\dfrac{F}{W + w}$.

PART III—MECHANICS OF FLUIDS

Exercise 20.—Prove that in a liquid at rest under gravity the pressure exerted is proportional to the depth, is the same in all directions and is independent of the amount of the liquid. (TEXT-BOOK, §§ 100-103.)

APPARATUS.—The pressure gauge consists of a small glass funnel (or *thistle-tube*) *A* (Fig. 31), over which is tied thin sheet rubber, such as dentists use. A rubber tube *B* connects the funnel to a U-shaped glass tube *C*, of small bore, in which is mercury or water which acts as a manometer (or pressure measurer). An increase of pressure on the sheet rubber forces it inwards and this will cause a difference in the levels of the liquid in the manometer, the amount of which can be measured. The funnel is held by a wire which passes into the lower end of a meter rod—(or into a block which is fastened to the rod)—in such a way that the funnel can turn about a horizontal axis in the plane of the rubber. In this way the rubber sheet may be made to face any direction. The rod is held in a clamp and can be raised or lowered.

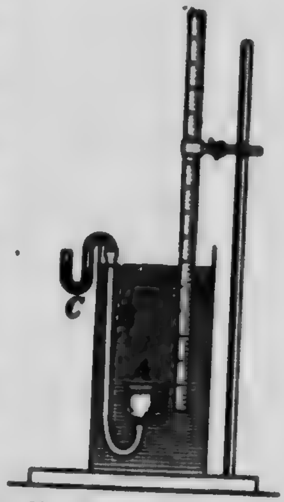

FIG. 31.—Apparatus for experiments on pressure exerted by a liquid.

Lower the funnel into the water (which should be at the same temperature as the room) until 2 or 3 cm. below the surface. Note the depth and observe the level of the liquid in the manometer. By means of a string attached to the funnel turn it so that it faces in different directions, and observe any change in the manometer. Be careful not to kink the tube.

Lower the funnel 4 or 5 cm. further; note the depth and the position of the index. Rotate as before and observe the index reading. Continue this until the bottom of the vessel is reached.

Next, pour the water into a smaller vessel and repeat the operations.

Tabulate the results in each case. Draw a curve in which ordinates represent depths of the rubber sheet and abscissas represent readings of the index.

Why is it undesirable to put the hand in the water to rotate the funnel?

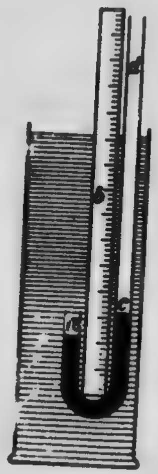

FIG. 32.—Manometer for investigating the relation between pressure and depth in liquids. The internal diameter of the tube should be at least ¼ inch.

What general laws do you infer regarding the pressure exerted by a liquid?

The pressure can be measured directly by means of a manometer *a d* with one of its branches longer than the other, without the thistle tube and connections, as shown in Fig. 32. In this case the water enters the short branch and presses directly on the surface of the mercury at *a*. The difference in levels *a* and *c* of the mercury for different depths is indicated by the scale on the graduated ruler *b*.

Exercise 21.—Find the loss of weight of a solid when immersed in a liquid. (Illustration of Archimedes' Principle.) (TEXT-BOOK, §§ 106-108.)

APPARATUS:—For this experiment use the balance, an overflow vessel *H* (Fig. 33), and a vessel *K* (a beaker or a metal can).

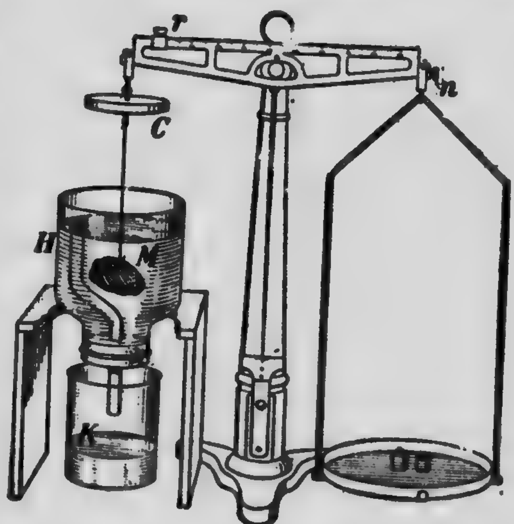

FIG. 33.—When the body *M* is immersed the water flows out through the bent tube into the beaker *K*.

First weigh the vessel *K*. Then remove the left pan of the balance and substitute for it the counterpoise *C*, which has as nearly as possible the same weight. If necessary adjust the balance to equilibrium by means of the nut *n*.

By means of a fine thread suspend from *C* a piece of iron (or other heavy object) *M*, and carefully weigh it.

Now gently lift M aside, and underneath C place the vessel H. Pour water in until it overflows, and allow the water to drip off. Then place the vessel K under the spout, and lower M into H, allowing it to hang freely in the water and catching in K the water which has overflowed.

Under these conditions weigh M again. The difference between this weight and the previous one will be the apparent loss in weight through immersion in the water, *i.e.*, the buoyant effect of the water.

Now weigh the vessel K, containing the overflowed water, and deducting the weight of the empty vessel, we obtain the weight of the water which overflowed, which is the water displaced by the object M. Compare this weight with the apparent loss in weight by immersion in the water.

FIG. 34.—Determination of volume of liquid displaced by a solid.

Instead of the overflow vessel a graduated tube (Fig. 34) may be used to determine the weight of the displaced water. The volume of the water displaced is read from the graduations, and the mass determined by multiplying this volume by the density of water.

Exercise 22.—By means of the balance find the density of a heavy body (a piece of iron, or aluminium or glass). (TEXT-BOOK, § 109.)

APPARATUS:—Balance used in Exercise 21.

Suspend the body from an arm of the balance and weigh it in air. Then weigh it when immersed in water. Find the loss in weight. This is equal to the weight of a volume of water equal to the volume of the body.

Then density (*in grams per c.c.*) =

$$\frac{\text{weight in air } (\textit{in grams})}{\text{loss of weight in water } (\textit{in grams})}.$$

Be careful to remove air-bubbles. What effect will they have?

If the temperature of the water rises what will be the effect on the density?

Exercise 23.—Find the density of a body which will float in water —a block of wood or of paraffin wax. (TEXT-BOOK, § 111.)

First Method. Weigh the wood by the balance. Then by means of a pin press the wood down into the water in an overflow vessel (Fig. 33, *H*) until it is entirely submerged. Catch the water and weigh it. This is the weight of the water displaced by the wood, which, divided into the weight of the wood in air gives the density.

Second method. Instead of using the balance place a graduate under the spout of the overflow vessel. Carefully lay the wood on the water in the vessel and observe the overflow into the graduate. Let it be x c.c.; its weight is x grams. Now press the wood down until entirely submerged, catching the water as before. Let it be y c.c., which weighs y grams.

Then the density (*in grams per c.c.*) $= x \div y$.

Third Method. Attach a sinker to make the wood sink in water.

1st. Weigh the body in air. Let this be m grams.

2nd. Attach a sinker and weigh both, *with the sinker only in water.* Let this be m_1 grams.

3rd. Weigh both, *with both in water.* Let this be m_2 grams.

Now the only difference between the second and third operations is that in the former case the body is weighed in air, in the latter in water. The sinker is in the water in both cases.

Hence $m_1 - m_2$ = buoyancy of the water on the body, and the density (in grams per c.c.) $= \dfrac{m}{m_1 - m_2}$.

A large screw or a piece of lead may be used as a sinker.

If a block of wood is used it should be soaked in hot paraffin. (Why?)

Exercise 24.—Find the density of a liquid by means of the specific gravity bottle. (Text-Book, § 112.)

Apparatus:—Alcohol and gasoline are suitable liquids. The most convenient bottle for the purpose is illustrated in Fig. 35.

First weigh the bottle empty and dry. Let the weight be w_1 grams. Then fill with water. There is a small hole in the stopper through which any excess of water escapes. Carefully wipe off the water and weigh again. Let the weight be w_2 grams. Empty the water, removing it all, fill with the liquid and weigh again. Let the weight be w_3 grams.

Fig. 35.—A specific gravity bottle.

Then it is evident that the density of the liquid (*in grams per c.c.*) =

$$\frac{w_3 - w_1}{w_2 - w_1}.$$

Exercise 25.—Find the density of a liquid by weighing a solid first in water then in the liquid. (Text-Book, § 113.)

Suitable liquids are alcohol, coal oil, gasoline.

First weigh the solid (a piece of glass or iron) in air, then in water and then in the liquid. Let the weights (*in grams*) be w_1, w_2, w_3, respectively.

Then $w_1 - w_2$ = weight of a volume of water equal to that of the solid,
and $w_1 - w_3$ = weight of a volume of the liquid equal to that of the solid.

Hence the density (*in grams per c.c.*) $= \dfrac{w_1 - w_3}{w_1 - w_2}$.

Exercise 26.—Compare the densities of two liquids which do not mix (water and oil).

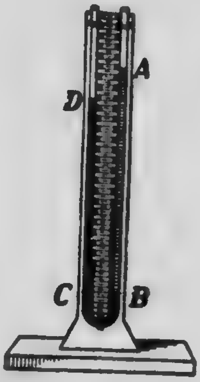

FIG. 36.—U-tube to compare densities of liquids.

APPARATUS:—Use a U-tube, mounted as shown in Fig. 36.

If the glass tubing is not more than $\frac{1}{4}$ or $\frac{3}{8}$ inch in diameter it may be bent in an ordinary flat gas-flame, and in place of a bent glass tube two straight pieces can be connected by a piece of rubber tubing securely bound on.

Pour water (through a funnel) into one limb of the tube until both limbs are about one-third full. Then slowly pour in oil until the surface of separation B, between the oil and the water, is well above the bend of the tube.

Let A be the free surface of the oil and D that of the water. It is evident that the height AB of oil balances the height CD of water, and so

$$AB \times \text{density of oil} = CD \times \text{density of water},$$

$$\text{or density of oil} = \frac{CD}{AB} \times \text{density of water}.$$

If the glass tubing is small some allowance should be made for capillarity. Hold pieces of the tubing in water and in oil and observe how far the liquids rise by capillary action. Estimate this in millimetres.

Turpentine or mercury may be used in place of the oil, but the latter is not so satisfactory. (Why?)

What would be the effect of having one limb of the tube larger than the other?

Exercise 27.—Compare, by means of balancing columns, the densities of two liquids which mix.

APPARATUS:—Suitable liquids to compare are water and a solution of copper sulphate or of common salt. The apparatus is illustrated in Fig. 37. The upright glass tubes are joined by rubber tubing to a 3-way glass tube, and the rubber tube E can be closed by a pinch-cock F.

FIG. 37.—Comparison of densities by balancing columns.

Fill one tumbler with water and the other with the copper sulphate (or other) solution and record the height to which each liquid rises by capillary action, the pinch-cock being open.

Apply the lips to the tube E and draw out some of the air, thus allowing the pressure of the air outside to force the liquids into the tubes. When the taller one reaches nearly to the top of the glass tube pinch the rubber tube and close the pinch-cock. Watch the columns to make sure that there is no falling in the surfaces through the connections not being tight. (Moisten the connections occasionally with a little glycerine to keep them air-tight). When sure that the columns are steady measure the heights AB, CD of the surfaces of the liquid columns above the liquid in the tumblers, and deduct from these the heights to which the liquids rose by capillary action.

As in Exercise 26, the densities are inversely as their heights.

Exercise 28.—Prove that a gas has weight. (TEXT-BOOK, § 115.)

Take a vessel (Fig. 38) which can be attached to an air-pump, weigh it, exhaust the air from it, close the stop-cock, and weigh it again.

What difference in weight is observed? What causes this difference? Allow the air to re-enter and observe the result. Has air weight?

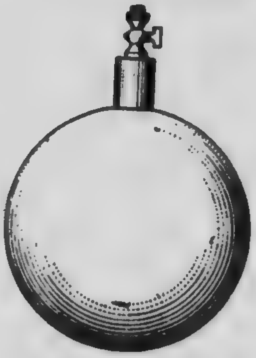

FIG. 38—Globe for weighing air.

Exercise 29.—Measure the pressure exerted by the atmosphere. (TEXT-BOOK, §§ 117-120.)

APPARATUS:—Use a heavy glass tube about 80 cm. long, closed at one end. The internal diameter of the tube should be at least $\frac{1}{4}$ inch.

Pour mercury into the tube until it is completely filled. Hold the finger over the open end and invert the tube, placing the open end under the surface of mercury in a dish. Support the tube in a vertical position and measure the height of the mercury in the tube above that in the dish. (Fig. 39.) Let it be h cm.

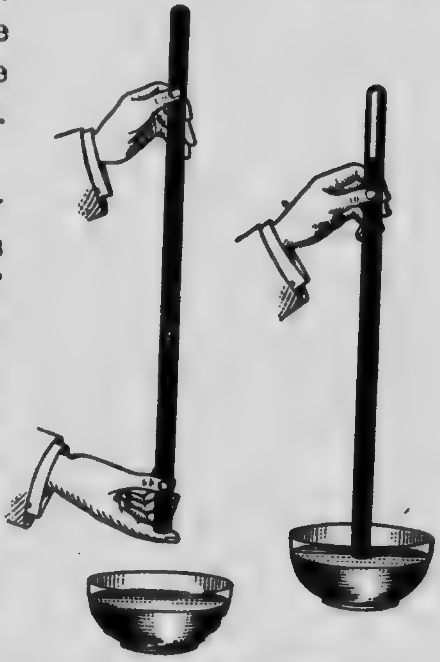

FIG. 39.—Measuring the pressure of the atmosphere.

Now the pressure exerted by a liquid depends only on its depth. Suppose the section of the tube to be 1 sq. cm. Then there would be h c.c. of mercury in the tube, and the weight of this is the pressure on 1 sq. cm., and as this is just balanced by the pressure of the atmosphere this is the atmospheric pressure required.

1 c.c. of mercury weighs 13.6 grams and hence the atmospheric pressure $= 13.6 \times h$ grams per sq. cm.

In performing the experiment it is necessary to get rid of the air bubbles as fully as possible. To do this, stop in the process of filling the tube several times, and, holding

the finger over the open end of the tube, slowly invert the tube several times. In this way most of the bubbles are collected, but they cannot be fully eliminated without boiling the mercury in the tube, to do which requires special apparatus.

Having the pressure in grams per sq. cm. compute it in pounds per sq. in. (See table, page 126.)

Exercise 30.—Study the action of the common pump. (Text-Book, § 142.)

Obtain a glass model of a common pump, and beginning with the pump empty, work the piston up and down observing the behaviour of the valves. Now lower the pump into a jar of water and observe (*a*) the action of the valves on (1) the up-stroke, (2) the down-stroke, (*b*) the action of the water within the suction-pipe and the barrel.

Explain the causes of the opening and closing of the valves in each of the above cases and also the upward movement of the water in the pump.

Exercise 31.—Study the action of the force-pump. (Text-Book, § 143.)

Procure a glass model of a force-pump, lower it into water and observe (*a*) the actions of the valves on (1) the down-stroke, (2) the up-stroke, (*b*) the action of the water in the suction-pipe, barrel and air chamber.

1. Explain the opening of the valves in each of the above cases and also the movement within the pump.

2. If the end of the outlet pipe is smaller than the pipe a continuous stream will tend to flow from it. Explain the action of the air chamber in producing this effect.

Exercise 32.—Study the action of the siphon. (Text-Book, § 145.)

Fill a glass tube of the form shown in Fig. 40 with water, stop each end, invert it and place one branch in a vessel filled

with water making sure the end of the other branch is below the surface of the water in the vessel. Unstop the ends of the tube.

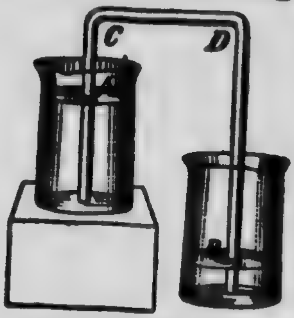

FIG. 40.—The siphon.

1. What takes place?

2. What is the cause?

To answer the last question consider,

(*a*) What is the pressure at A tending to move the water in the direction AC?

(*b*) What is the pressure at B tending to move the water in the direction of BD?

(*c*) Which is the greater of these forces? Why?

Exercise 33.—Measure the pressure of the gas in the city mains, or in a vessel into which air is pumped.

Use a U-tube as shown in Fig. 41. Pour water (coloured, if desired, with a little aniline dye) into one end of the tube. It will take, of course, the same height in each arm. Take this height above the base. What is the pressure on each surface now?

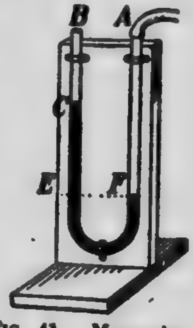

FIG. 41.—Measuring the pressure of the gas.

Attach one end A of the tube, by means of a rubber tube to a gas-tap, and turn on the gas. The column of water in A will be depressed, that in B raised. Read the height of each column, and deduce the difference in the levels.

It is evident that the pressure of the gas at F is equal to the pressure of the atmosphere + that due to a column CE of water.

Calculate this pressure in grams per square cm.

Would this height be changed if the diameter of the tube were increased?

If a city gas supply is not available, measure the pressure in a bottle into which air is forced by a bicycle pump attached to the rubber tube *A* (Figure 42) which is attached to a glass tube passing through the stopper.

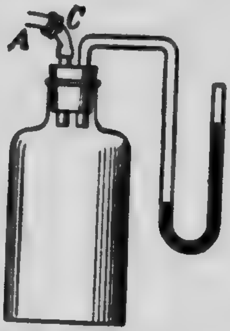

FIG. 42.—Measuring the pressure of the air in a bottle.

Find the difference in level produced by one full stroke of the pump, then by two, three, four, etc., strokes, a pinch-cock *C* being used to prevent the air from escaping.

Instead of glass tube and pinch-cock a bicycle tire valve may be passed through the cork.

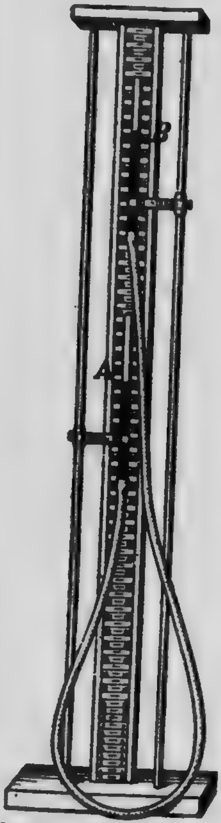

FIG. 43.—Boyle's Law apparatus. *A*, closed tube; *B*, open tube.

If alcohol or mercury had been used instead of water what would be the difference in the levels?

Exercise 34.—Find the way in which the volume of a given mass of gas changes when its pressure is changed, the temperature being kept constant (Boyle's Law). (TEXT-BOOK, § 129.)

APPARATUS:—The apparatus shown in Fig. 43.

Two glass tubes, *A* and *B*, are supported in such a way that either may be raised or lowered. The upper end of *A* is closed, that of *B* is open, and their lower ends are joined by a heavy rubber tube. The rubber tube and part of *A* and *B* are filled with mercury. When the mercury is at the same level in both glass tubes *A* should be about half-full of dry air. The tube *A* is of uniform bore and the volume of the air may be taken proportional to the length of the tube occupied by it, this being obtained from the scale against which it is placed.

Read the barometer and record its height in cm. of mercury. When the mercury is at the same level in both tubes the air is under the pressure of one atmosphere, *i.e.*, the pressure shown by the barometer.

Now lower *B* as far as it will go. Do this rather slowly. Then take the levels of the mercury in the two tubes. The pressure exerted by the imprisoned air is now 1 atmosphere − the difference in levels of the mercury. Raise *B* a few cm. and take the readings again. Continue this until *B* is as high as it can go. When the level of *B* is above that of *A* the pressure on the imprisoned air is 1 atmosphere + the difference in level.

The tube *A* should not be handled for fear of raising the temperature of the inclosed air. For the same reason the air should not be compressed or expanded quickly.

Tabulate your results as follows:—

Level of Mercury in		Difference between the Levels.	Height of Barometer.	Total Pressure in cm. of Mercury = *P*.	Length of Air in Tube = *V*.	Product $P \times V$.
Closed Tube.	Open Tube.					

Draw a curve having the values of *P* for ordinates and those of *V* for abscissas.

The following method employs more simple apparatus and gives accurate results: Take a piece of glass tubing 1 metre long with a very small bore (not more than 1 mm.). Half fill it with mercury by suction; then holding it horizontally, seal

the end away from the mercury in the lamp flame. The air shut in the tube is the quantity whose volume is to be measured. Measure the length of the air column (1) when the tube is horizontal, (2) when vertical with the open end up, (3) when vertical with the open end down. If p is the height of the barometer and l is the length of the mercury column in the tube, the pressure in the first case is p, in the second case $p-l$, and in the third case $p+l$. Results may be tabulated as follows:

No.	Volume = V.	Pressure = P.	Product $P \times V$.
1	$V_1 =$	$p =$	
2	$V_2 =$	$p - l =$	
3	$V_3 =$	$p + l =$	

Part IV—Sound

Exercise 35.—A study of the origin of sound. (Text-Book, §§ 191, 192, 218.)

All bodies when producing sound are in a state of vibration. Clamp a knitting needle or a narrow strip of steel in a vice so that about 15 cm. projects. Draw the free end aside and let it go. A low deep note is emitted, and you can *see* that the end of the needle is vibrating. Touch the tip of your finger to it; contact with the finger stops the vibration and at the same time the sound ceases. Shorten the projecting portion, and examine the motion again. What difference do you observe in the nature of the vibration and of the note? Do you observe any connection between the loudness of the sound and the amplitude of the vibrations? Do you detect any relation between the length of the vibrating strip, the frequency of the vibrations and the pitch of the note?

Cause a bell to sound by striking it with a pencil or a bit of wood, and while it is sounding hold a pith ball (or other light object) on the end of a thread so that it rests lightly against the rim of the bell. What result do you observe? Explore all about the rim; do you detect any difference as you go about it?

Sound a tuning-fork by rubbing a violin bow over one of the prongs or by striking it with a soft rubber stopper on the end of a stick. Examine it with the suspended pith ball. Touch the prongs to the surface of water. Hold the stem of the vibrating fork on a board (the top of a table). Why is the sound louder?

Sprinkle sand lightly but evenly over a square or a circular brass plate clamped at the centre. Draw a bow vertically

across the edge of the plate. Practise bowing steadily and uniformly until you can produce a clear note. Observe the figure assumed by the sand. Touch the tip of a finger against some point on the edge of the plate and bow again. Then touch the plate in two places and bow Sketch the figures in your note-book and describe the sound heard with each. Why does the sand take up its position along certain lines? What name is given to those lines. In your note-book give a full account of what you observed.

Cut off the mouth-end of a common wooden or metal whistle about midway between the first and second holes, and insert it tightly through a cork in one end of a glass tube. The tube may be about 1 inch in diameter and 10 inches long, and should be closed at the other end. Into the tube, before closing it, put some powder made by rubbing a baked cork on a file or on sandpaper. Now hold the tube in a horizontal position and blow the whistle. Describe the behaviour of the powder. What do you conclude as to the condition of the air when the whistle is sounding. How can you show that the sound does not come from vibrations of the substance composing the whistle or the tube?

Exercise 36.—Determine the velocity of sound in air by means of a stop-watch and a gun. (TEXT-BOOK, § 193.) *An alternative method is given in the next exercise.*

APPARATUS:—Two observers are required, one provided with a gun, the other with a stop-watch.

On a quiet day let the two observers take positions about a mile apart, each in full view of the other. When ready the one with the gun waves a flag—or if at night, a lantern—to call the other's attention. He then fires the gun. Immediately on seeing the flash the observer with the watch starts it, and on hearing the report he stops it again. The time thus recorded is the time required for the sound to travel the distance between the observers. The time required for the light to travel this distance is neglected, it is so excessively

short. If a stop-watch is not available an ordinary one may be used but it is not nearly so satisfactory. Calculate the velocity per second. For convenience the one with the watch should have a flag or a lantern too.

Make as many observations as possible and take the average. If in the country the distance may be found from concession or side-lines; if in a town a map of the place may be consulted.

If a breeze is blowing, the observers should interchange positions and thus obtain the velocity in each direction. Take the mean of these as the velocity in still air.

Take the temperature of the air at the time, and assuming that the velocity decreases 60 cm. or 2 ft. for a fall of 1° C., calculate the velocity at the freezing point.

Exercise 37.—Determine the velocity of sound in air by means of a pendulum. (*Alternative method to Exercise 36.*)

APPARATUS:—The apparatus is shown in Fig. 44. The upright *A* is about 1 m., and *B* and *C* are about 30 cm. high. *B* and *C* are attached to the front of the base with a slit 5 cm. wide between them. *A* is attached to the back of the base, and in front of it is a pendulum which swings back and forth. The pendulum bob is large and painted bright white, while the rest of the apparatus is painted black, so that the bob can be easily seen as it passes the slit between *B* and *C*.

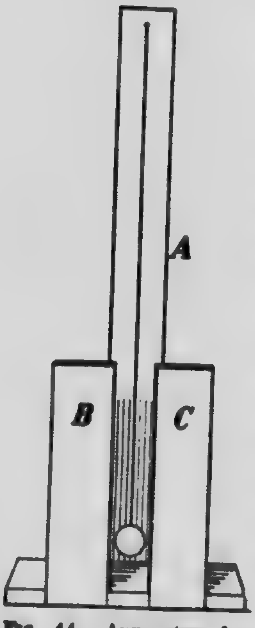

FIG. 44.—Apparatus for velocity of sound.

One boy hides behind the apparatus, and as the pendulum reaches one extreme of the swing he strikes with a hammer against a piece of metal. A second boy moves back until he hears the sound at the instant he sees the pendulum pass the slit. In this case the sound has travelled to the boy while the pendulum made one-fourth of a complete vibration. This second boy should have field-glasses or a spy-glass, if possible.

The distance can be measured with a tape measure or a measured rope. The time of a complete vibration of the pendulum can be obtained from the formula:

$$T = 2\pi\sqrt{\frac{l}{g}},$$

where T = time in seconds, l = length of pendulum from point of suspension to middle of bob in cm., and $g = 981$, the measure of the acceleration of gravity.

Exercise 38.—Find the wave-length of a sound. (TEXT-BOOK, §§ 219–221.)

APPARATUS:—A convenient form of apparatus for this experiment is shown in Fig. 45. The glass tube AB is about 3 cm. in diameter and as long as convenient (1 m. if possible). In the lower end is a rubber stopper through which passes a glass tube, and from this a rubber tube runs to a funnel C. Water is poured into the funnel, and by raising or lowering it the level in AB can be altered.

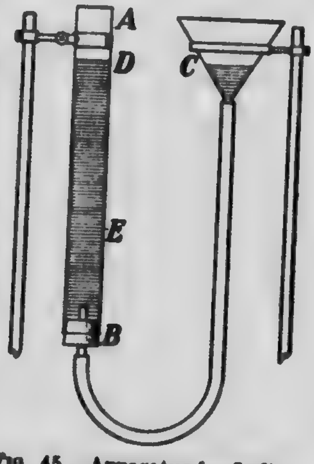

FIG. 45.—Apparatus for finding the wave-length of sound.

Hold a vibrating tuning-fork over the open end A; then raise or lower the water in AB until a level D is found at which the sound of the fork is re-enforced most strongly. Mark the position of D by a bit of wet paper.

Measure the length of the air column AD. This is approximately one-fourth of the wave-length of the sound produced by the fork. Strictly, this length depends somewhat on the diameter of the tube. To obtain the quarter-wave-length we should add $\frac{2}{5}$ of the diameter of the tube, *i.e.*, one-fourth of the wave-length of the sound = length $AD + \frac{2}{5}$ of diameter of the tube.

If the tube is long enough lower the water in it until another resonating length AE is obtained. Mark E also with

wet paper. The distance DE is one-half of the wave-length of the sound.

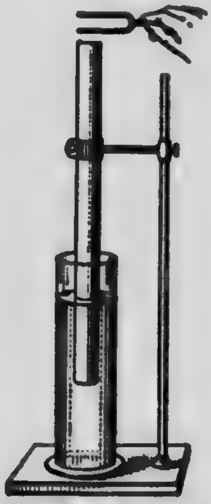

FIG. 46.—Resonance apparatus for velocity of sound.

Determine the wave-length several times both by measuring AD, and DE, and compare the values thus obtained.

Having thus obtained the wave-length, and knowing the number of vibrations per second given by the fork, we can find the velocity of the sound from the formula $v = nl$.

If the above apparatus is not obtainable one may raise or lower a tube immersed in a vessel containing water, thus varying the length of the air column (Fig 46); or by moving in the tube a well-fitting piston the same result may be obtained.

Exercise 39.—Find the velocity of sound in glass or in metal. (By Kundt's Method.) (TEXT-BOOK, §§ 198, 199.)

FIG. 47.—Apparatus for finding the velocity of sound in a solid.

APPARATUS:—The apparatus consists of a glass tube 1 m. or more in length and 3 or 4 cm. in diameter held on a base. It is closed at one end by a tightly-fitting piston A, and in the other end is a loose piston B, made from a thin cork cemented to the end of a long glass (or metal) rod or tube 1 cm. or so in diameter. The rod is securely clamped at its middle C. Soft cotton cord may be wrapped about the circumference of the cork piston in order to fit the tube snugly and still move with no appreciable friction against the wall of the tube.

Distribute evenly in the large tube a little cork-dust made by rubbing a baked cork against a file or sandpaper. Then excite longitudinal vibrations in the glass rod by gently stroking it from the centre towards the free end with a damp cotton cloth. A little practice will enable one to produce a

clear high note. Be very careful not to break the rod. The middle of the rod remains at rest, the ends moving in and out, and the motion of the piston B sets up condensations and rarefactions in the air which travel onwards to the piston A, and, upon reflection there, meet others coming onwards, and thus produce standing waves.

Adjust the position of the piston A until when the rod is rubbed the cork-dust is violently agitated and settles into parallel ridges with uniform spaces between. Unless the adjustment is exact the end ridges will not be perfect. The dust gathers where the agitation is least, and the loops are half-way between. The distance between successive nodal lines is one-half the length of the sound-wave in air. Measure with a metre rod the distance between two well separated nodes, and divide by the number of groups of ridges. Twice this distance will be the wave-length of the sound in air. Let it be l_1.

As the rod is clamped at the middle the length of the rod is one-half of the wave-length of the sound in the glass, and hence the wave-length in the glass is equal to twice the length of the rod. Let it be l_2. Now the frequency of the sound is the same in both the air and the glass, and by using the formula $v = nl$ we have the relation,

$$\frac{\text{Velocity in glass}}{\text{Velocity in air}} = \frac{\text{wave-length in glass}}{\text{wave-length in air}} = \frac{l_2}{l_1}.$$

With a thermometer take the temperature of the air in the neighbourhood of the glass tube. Let it be t°C. Then the velocity in air $= 332 + 0.6t$ m. per second, and the

$$\text{Velocity in glass} = \frac{l_2}{l_1} \times (332 + 0.6t) \text{ m. per second.}$$

A glass rod is easiest to vibrate but it breaks easily. Instead of it a rod of brass or of wood may be used. These can be put in vibration by stroking with leather covered with powdered rosin. A mit faced with chamois answers very well.

Exercise 40.—Find the vibration-frequency of a tuning-fork.

APPARATUS:—The apparatus (Fig. 48) consists of a large tuning-fork with a light aluminium or brass style, or a bristle, attached to one prong; a pendulum which beats approximately quarter-seconds with a style extending below the bob (which should be heavy); and a piece of smoked (or whitened) glass, about 10 × 30 cm., on a carriage which can be drawn along under the two styles. The glass may be smoked by holding it over a lamp-flame, with the chimney removed, or even over a candle; it is much cleaner, however, to coat it with a mixture of whiting in alcohol or of "Bon Ami" soap.

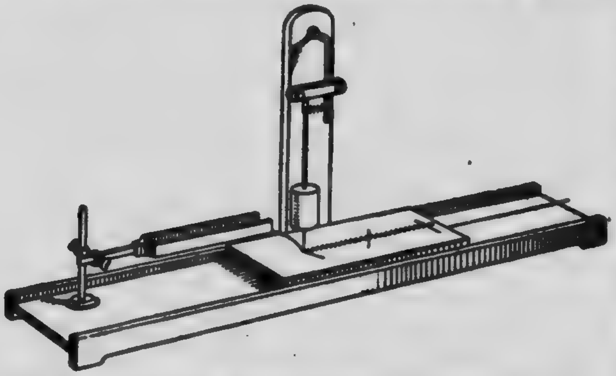

FIG. 48.—Comparing the frequency of a pendulum and a tuning-fork.

Adjust the height of the pendulum so that the style barely touches the coated surface of the glass. Then carefully adjust the tuning-fork so that its style bears lightly on the glass, and when vibrated makes a stroke on the glass parallel to the pendulum's motion across the glass. Both motions should also be at right angles to the direction of motion of the glass when pulled along on its carriage. For best results, the two styles when at rest should be in a vertical plane, with their points as near together as practicable.

Set the tuning-fork in vibration by bowing it. When it is going properly draw the pendulum aside and let it swing, and then quickly draw the glass along beneath the styles. The writing on the glass will be like Fig. 49. Between *A* and *B*, *B* and *C* are single swings of the pendulum. Count the number of vibrations of the fork between the first and the last swing

FIG. 49.—The trace of the tuning-fork and the pendulum.

of the pendulum recorded on the glass. Next count the number of vibrations of the pendulum per minute and deduce the time of a single one. Then calculate the number of complete (*i.e.*, to-and-fro) vibrations of the tuning-fork in one second.

Exercise 41.—A study of pitch. (TEXT-BOOK, §§ 202-204, 212.)

APPARATUS.—Toothed wheels, perforated disc, stretched strings.

Hold a card lightly against the teeth of a toothed wheel (Fig. 50) and rotate the wheel, at first slowly, then more and more rapidly. Observe the sound produced. When the wheels are rotating touch a card to each in succession, and note the difference in the sounds. Count the number of teeth on the wheels.

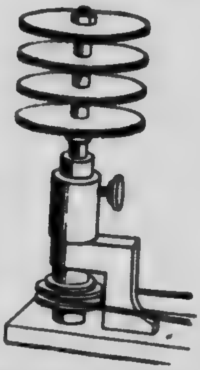

FIG. 50.—Toothed wheels on a rotating machine.

Rotate the disc shown in Fig. 51, first slowly, then more rapidly, at the same time forcing air steadily through the tube.

Describe the changes which take place in the sound produced in each of the above experiments as the velocity of the rotating wheel or disc is increased. What is the cause of the sounds? On what does the *pitch* of a sound depend?

Next use a sonometer (see Fig. 52). Stretch a piano wire by means of a weight, and then pluck it. Note the pitch. Then shorten the wire by inserting a movable bridge under it and pluck again. Is the pitch higher or lower than that given by the string vibrating as a whole?

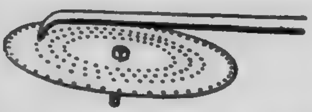

FIG. 51.—Air is blown through the holes in the rotating plate.

Take out the movable bridge and pluck the string again. Mark the original note. Now add another weight, thus increasing the stretching force, and again pluck the string.

What change has increasing the tension of the wire made in the pitch of the note?

Take two piano wires of different diameters and stretch them in turn on the sonometer with the same weight? Which wire gives, when excited, the higher note?

Procure two wires of the same diameter, but of different densities (such as steel and brass or copper), and stretch them in turn on the sonometer with the same weight. Which gives the higher note? Which is the denser (see table on page 126)?

State in general terms how the pitch of the note given by a vibrating string depends upon its length, its tension, its diameter and its density. These relations are considered more minutely in Exercise 42.

Exercise 42.—Investigate the laws of vibrating strings. (TEXT-BOOK, §§ 212, 213.)

APPARATUS:—Use a sonometer having at least two strings. One of these is fixed at one end while at the other end it is wound about a post which may be turned with a key, thus altering the tension as desired. The other string is fastened at one end, while at the other it passes over a pulley and has a hook on the end of it to which weights may be added. Let the first string be of steel wire No. 22: we shall call this string A. In addition have a second steel string of the same gauge, which will be called string B; and a steel string No. 28 gauge (*i.e.*, with a diameter one-half that of the other). Call this latter string C.

1st. Investigate the relation between length and pitch. Stretch string B with sufficient weight (6 or 8 kg.) for it to give, when plucked by the finger or excited by a violin bow, a good musical note. Then alter the tension of string A until the two strings are in unison. Do this by listening for the beats produced when the two strings are sounded together. When unison is obtained there will be no beats.

Now place a bridge under string B a few cm. from one end and pluck the longer portion of the string, pressing the short

portion down on the bridge. What effect on the pitch? Move the bridge until a length is reached which gives a note an octave above the original string. Measure the length required.

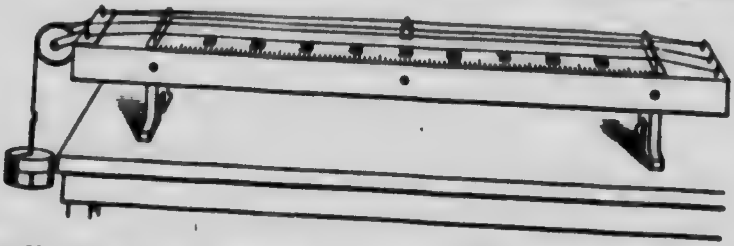

FIG. 52.—A sonometer, consisting of stretched strings over a thin wooden box. By means of a bridge we can use any part of a string.

Compare by plucking string *A*. If one note is an octave above another it has twice as many vibrations per second. What relation do you observe as to length and number of vibrations?

Mark off on the sonometer lengths which are respectively $\frac{8}{9}$, $\frac{4}{5}$, $\frac{3}{4}$, $\frac{2}{3}$, $\frac{3}{5}$, $\frac{8}{15}$, $\frac{1}{2}$ of the original length. Sound the notes given by these lengths. They produce the major diatonic scale, the frequencies of which are in the ratios 1, $\frac{9}{8}$, $\frac{5}{4}$, $\frac{4}{3}$, $\frac{3}{2}$, $\frac{5}{3}$, $\frac{15}{8}$, 2. What law do you observe between pitch and length?

2nd. Relation between pitch and tension. Apply a tension of 3 kg. to string *B*, and tune *A* to be in unison with it. Then place the bridge so as to use one-half of *A* and add weights to *B* to bring it into unison with one-half *A*. Compare the new with the old pitch, and the new with the old tension. What relation do you find?

3rd. Relation between pitch and diameter. Put a weight of, say, 6 kg. on string *B*, and adjust the tension of *A* until it is in unison with *B* again. As the strings are of the same diameter, length and material, it is clear that string *A* is also under a tension of 6 kg. Now substitute string *C* for string *B* and add the same weight 6 kg. Thus strings *A* and *C* are under the same tension. Pluck *C*; its pitch is much higher

than that of *A*. Adjust the bridge under *A* until you obtain a length which gives a note in unison with that given by *C*. Measure this length. What is the difference in pitch between strings *C* and *A* when at full length? Measure with a wire gauge the diameter of the wire.

What relation do you observe between pitch and diameter? State the three laws you have obtained.

Exercise 43.—Investigate the nodes and loops of a vibrating string. (TEXT-BOOK, §§ 189, 214.)

APPARATUS:—A sonometer and some small paper riders. (Fig. 53.)

Damp the string at the centre by touching it lightly with a feather or with the tip of the finger. Place a rider, made by folding a piece of paper, as shown in the figure, at the middle of one of the halves, and bow the string at the middle of the other half. How does the rider behave? How is the string vibrating?

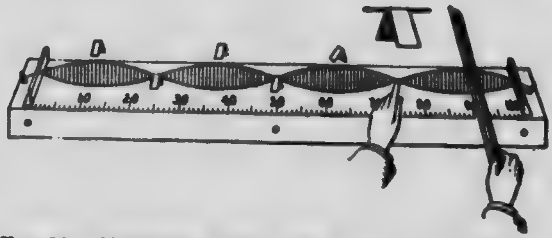

FIG. 53.—Obtaining nodes and loops in a vibrating string. The paper riders stay on at the nodes, but are thrown off at the loops.

Repeat the above experiment, damping the string at one-third its length from one end, placing riders on the string at $\frac{1}{6}$, $\frac{1}{3}$ and $\frac{1}{2}$ its length from the other end. How do the riders behave? Where are the points of least motion in the string? Where the points of greatest motion? How is the string vibrating?

Repeat the last experiment, damping the string at a point $\frac{1}{4}$ and then $\frac{1}{5}$ of its length from one end. How does the string vibrate in each case? How does the note which the string yields differ from that when it vibrates as a whole?

What are the points of least motion called? What those of greatest motion?

Exercise 44.—A study of flame-pictures given by sounds. (Text-Book, §§ 227, 228.)

Apparatus:—For this experiment we require a manometric capsule and a rotating mirror. A simple form of capsule, illustrated in Fig. 54, can be constructed by anyone. *AA* is a round piece of wood or of cork, about 5 cm. in diameter, hollowed out and having a membrane (of very thin rubber or of gold-beaters' skin) stretched over. This is held in position by a ring *BB*, screwed or pinned to *AA*. Gas enters by a tube *C* and leaves by a bent glass tube *D*, drawn to a point, at which place the gas is lighted. On speaking before the diaphragm it vibrates back and forth, and these vibrations cause the flame to dance up and down, but as the motions are so rapid the eye cannot follow them. In order to separate the images of the flame a plane mirror is rotated near the jet, which is viewed by reflection in the mirror. A simple form of mirror is shown in Fig. 55. It consists of a block of wood with metal rods projecting from the upper and lower faces respectively, while pieces of mirror are tied on the vertical faces of the block. The lower rod rests on a block and by taking hold of the upper rod the mirror can be rotated about a vertical axis. In order to intensify the action of the sound-waves on the diaphragm a funnel may be used, but the capsule works satisfactorily without it.

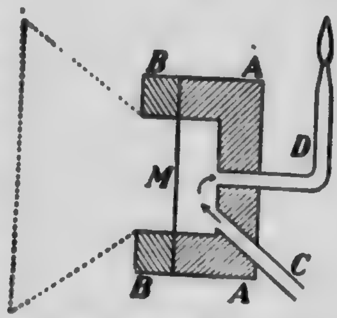

Fig. 54.—A simple form of manometric capsule.


Fig. 55.—A simple rotating mirror.

Admit, now, illuminating gas to the capsule and light it as it escapes through *D*, and adjust the flow until the flame is about 1½ cm. high. Rotate the mirror before the flame and observe the image. If the flame is at rest the image will be a simple band of light across the mirror. Now speak into the funnel and observe the image. Vibrate a tuning-fork and hold it before the funnel. If the fork is mounted on a resonance box hold the mouth of the box before the funnel. Then try a fork of higher pitch. What difference in the

flame-picture? Sing, with considerable intensity, *oo* (as in pool), and *a* (as in father), first low-pitched then high-pitched —an octave higher if possible—and observe the effect.

In your note-book describe all the experiments you have tried and sketch the flame in each case.

Exercise 45.—Experiments to show interference of sound-waves. (Text-Book, §§ 233, 234.)

Apparatus:—That shown in Fig. 46 and in Fig. 56.

1. Adjust the length of the air column over the water (Fig. 46) until it resounds most loudly when the fork is vibrated over the mouth of the tube. Then rotate the fork on its axis. Describe any changes in the sound. At what position of the fork is the sound loudest? At what position is it most feeble? Holding the fork in the position of weakest sound, carefully slip over one prong a small paste-board tube. What effect on the loudness of the sound?

2. Hold a vibrating fork near the ear and rotate it about its axis. Describe the sound, and account for the changes in it.

3. Tune two wide-mouthed bottles to resonance with the fork. In order to do this, hold the vibrating fork over the mouth of the bottle, and then carefully slip a microscope slide over it until the bottle resounds loudly. Then fasten the slide in place with soft wax. Now arrange the bottles as shown in the figure. Bring the fork slowly down to the position shown in the figure. What change in the sound occurred as the fork was put in this position? Hold a card over one mouth; what change in the sound? Account for this.

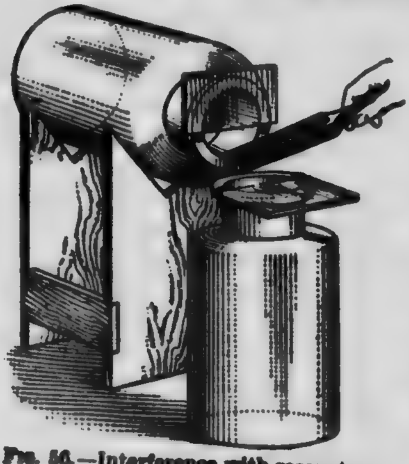

Fig. 56.—Interference with resonators.

Exercise 46.—Find the wave-length of a sound by interference in a divided tube. (TEXT-BOOK, §§ 189, 231.)

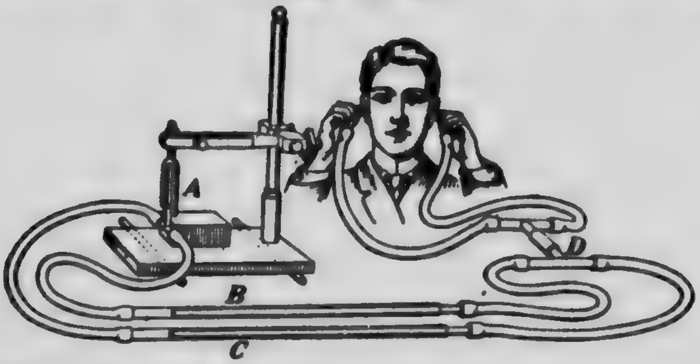

FIG. 57.—The fork A is held in a clamp of a retort stand which rests on rubber tubing to prevent the sound from being transmitted to the table on which it rests.

APPARATUS:—The apparatus consists essentially of two large T-tubes connected by rubber tubing (Fig. 57).

Let a sounding tuning-fork be placed before the open tube A. The sound passes along the tube and is divided by the first T-tube into two portions. One portion goes by way of the tube C, the other by way of the tube B, to the second T-tube, by which they are brought together again at D. Thence the motion is conveyed by the two tubes which lead to the ear. B and C are double tubes, one slipping snugly within the other.

It is evident that if the difference in the lengths of the tubes B and C is a half-wave-length of the sound used, the two components on reaching D will be in opposite phases, condensation in one will coincide with rarefaction in the other, and each will annul the effect of the other. Under these circumstances the two portions *interfere*, and there should be no sound heard at the ear.

A fork whose frequency is between 300 and 400 complete vibrations per second should be used. Let one student vibrate the fork before A, and another place the ends of the tubes in his ears. By slipping one glass tube over the other, vary the

difference in the lengths of B and C, and carefully adjust it until the sound is weakest. Pinch one of the tubes to compare the effects obtained by using one component and the two combined. Since the sound is transmitted not only within the tubing, but also by the material of the tubing, it will be impossible to extinguish the sound completely.

Having found the adjustment which gives the weakest sound, measure the lengths of the two paths, ABD, and ACD. Twice the difference between the two lengths is the wave-length of the sound.

If the frequency of the fork is known, calculate the velocity of sound from the formula $v = nl$; if it is not known, determine the frequency from the same formula, taking the velocity in metres as $332 + 0.6t$, where t is the temperature in degrees centigrade.

Exercise 47.—Test the freezing and the boiling point of [a ther]mometer. (TEXT-BOOK, § 258.)

APPARATUS:—Convenient apparatus is shown in Figs. 58, 59.

The freezing point. Insert the thermometer into a funnel (Fig. 58), containing clean ice broken into small pieces, packing the ice well about it. Allow it to remain for some minutes, until the mercury will fall no further, and then carefully take the reading. In doing so have the eye in such a position that a line drawn from it to the top of the mercury column is at right angles to the thermometer, and estimate the reading to tenths of a degree. Note carefully the reading on the thermometer. What should the reading be?

FIG. 58.—Apparatus for testing the freezing-point.

The boiling point. A convenient apparatus for testing the boiling point is shown in Fig. 59. Put rain or distilled water to the depth of 3 or 4 cm. in the boiler and screw the top on firmly. The height of the water is shown in the gauge *A*. The U-tube *M* is a mercury gauge, to measure the pressure within the boiler. Thrust the thermometer down through the perforated stopper until the point marked 100° C. (or 212° F.) can just be seen above the stopper. The bulb of the thermometer, however, must not be in the water, but in the steam above it.

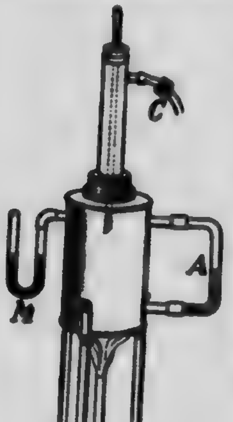

FIG. 59.—For testing the boiling point.

Keep the water boiling so that the stem of the thermometer is surrounded by steam, which escapes at *C*. See that there is always plenty of water in the boiler; and be careful that the flame does not flare out beyond the bottom of the boiler and burn the rubber connections of the gauges *A* and *M*

Read the thermometer after the mercury becomes steady and record its height in your note-book. Read the barometer and compute what the true boiling point is. How much in error is the thermometer?

[NOTE.—At 76 cm. the boiling point is 100° C., and an increase of 1 cm. raises the boiling point 0.4° C. At 29.92 inches the boiling point is 212° F., and an increase of 1 inch raises it 1.7° F.]

Effect of increased pressure on the boiling point. Next, partly close the rubber tube *C* by a pinch-cock. Keep the flame burning well and watch the thermometer and the mercury gauge *M*. Adjust the pinch-cock until the pressure in the boiler, as shown by the difference in level in *M*, is 4 or 5 cm. of mercury. Keep this pressure steady for some time and then record it, at the same time reading the temperature shown on the thermometer.

Now loosen the pinch-cock and allow the air to have free access to the boiler. After noting the reading of the thermometer again, draw it up until only the bulb and a short part of the stem is within the boiler. Watch the effect on the mercury as the stem cools. Record the reading. How much, from your results, is the boiling point raised by an increase in the pressure of 1 cm.?

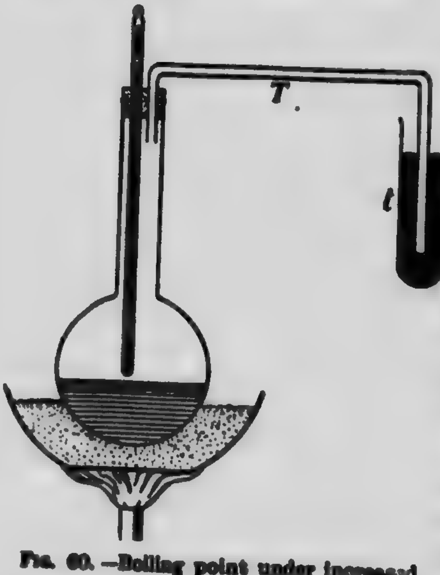

FIG. 60.—Boiling point under increased pressure.

If a boiler such as that shown in Fig. 59 is not available, the thermometer may be hung in a long-necked flask heated in a sand-bath. Care should be taken to have the bulb and stem both surrounded by steam. In Fig. 60 is shown how this apparatus can be used to investigate the effect of increased pressure on the boiling point. The steam passes from the flask by means of the tube *T*, the end of which is immersed in mercury contained in a test-tube *t*. Under what pressure is the steam?

Exercise 48.—Find the coefficient of linear expansion of a metal rod. (Text-Book, § 262.)

Apparatus:—The arrangement shown in Fig. 61 is well suited for this experiment. *B* is the boiler used in the last exercise (Fig. 45). Put about 3 cm. of water in it and a flame underneath it. *T* is a horizontal brass jacket tube covered with non-conducting material. Two smaller tubes, *H*, *K*, are soldered into this tube, steam entering at one and passing out at the other. A third tube at the middle, closed by a cork, has a thermometer *G* fitted into it. The rod to be experimented on is placed within *T*, which is closed by conical metal caps which keep the rod central in *T*. This tube is carried on a rigid base being held securely in place by clips. There are two uprights *A* and *C*, one at each end, firmly fastened to the base. One of these carries an adjusting screw *E*, and the other a micrometer *S*, which should read to 0.01 mm.

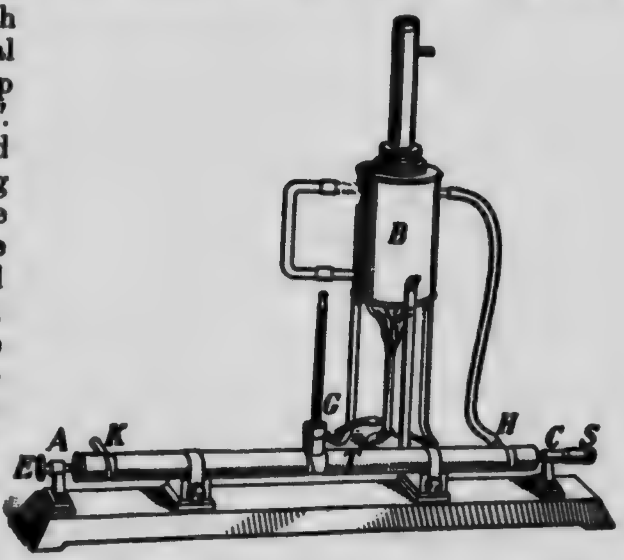

Fig. 61.—Apparatus for finding the coefficient of linear expansion of a metal rod.

First measure the length of the rod by means of a metre stick. Then place it in the jacket *T*, and, having one end firm against the screw *E*, turn the micrometer screw *S* until it makes gentle contact with the other end. Take the reading of the micrometer and also that of the thermometer, which gives the temperature of the rod. Then turn the screw back two or three rotations to allow for the expansion of the rod.

Now connect the boiler and allow the steam to pass freely through for some time, until the rod has had time to be heated through and the thermometer is steady. Catch the condensed

steam in a vessel placed under K, not on the base of the apparatus. Then turn the micrometer screw until it again makes gentle contact with the end of the rod. Record the temperature and read the micrometer. The micrometer readings must be taken with great care since the expansion is a very small quantity and any error made in measuring it will make a great difference in the final result.

Tabulate results as follows:—

Length of Rod in mm.	Temperature.		Micrometer.		Increase in Temperature.	Expansion in mm.	Expansion for 1° C.
	First.	Last.	First.	Last.			

The coefficient of linear expansion is the expansion per degree per unit of length, and is obtained by dividing the last column by the first. Calculate it and compare its value with that given in the TEXT-BOOK.

As the second temperature is that of the steam, this may be found by reading the barometer and then looking up the temperature of steam corresponding to that pressure. It will not vary much from 100° C. (See "Note" on page 52.)

Repeat the experiment, if possible. Accurate results are not easy to obtain.

A somewhat simpler apparatus is shown in Fig. 62. AB is a brass tube about 7 mm. in diameter and a little over a metre long, connected to a Florence flask or other boiler by a rubber tube M. By boiling water in the flask steam can be made to pass through AB. One end A of the tube rests in a groove in a block with the end close against a nail driven in the groove. A weight W keeps the end in its place. The other end rests

upon a piece of knitting needle lying on a piece of glass G. A light pointed stick c is fastened to the end of the needle and can move about a semi-circular card marked in degrees fastened

Fig. 62.—Finding the coefficient of expansion of a brass tube.

to the end of the block. The diameter of the needle can be measured with the wire gauge (Fig 11), or by measuring six of them laid side by side.

First, measure the length of the tube from the end A to the needle, and take its temperature as that of the air. Then pass steam through the tube for a few minutes, and observe the number of degrees the pointer c moves over. Let this be n, and let the diameter of the needle be d mm. Then the circumference of the needle $= \pi d$ mm., and as the needle has turned through $n/360$ part of a complete rotation, the expansion of the rod is $\frac{n}{360} \times \pi d$ mm.

Tabulate the results as above, but in place of the fourth and fifth columns, use a single column with heading "Degrees turned through."

Fig. 63.—To compare expansions of liquids.

Exercise 49.—Compare the expansions of water and alcohol. (TEXT-BOOK, § 263.

APPARATUS :—Obtain two bulb-tubes of equal size; or if these cannot be secured take two small flasks, as nearly alike as possible. Fill one with water, the other with alcohol (or methylated spirits). The temperature of each should be the same. Insert glass tubes of

small bore into two corks and push these into the bottles until the liquid rises to the same height in each, as shown on an attached paper scale. Observe the temperature. This may be done by allowing the flasks to stand until you are sure they have the temperature of the room, which is read by a thermometer placed near them; or the thermometer may be tied against the tube of each and allowed to take the same temperature.

Now place the two flasks in a vessel containing water a few degrees warmer. Watch closely any change in the heights of the liquids on immersing the two flasks. Allow them to stand for some time until they take the temperature of the water, and record the heights and the temperature. Then raise the temperature by heating or by pouring in warm water, and again take the temperature and the heights of the columns. Continue this until the alcohol is nearly at the boiling point or the liquids are at the top of the small tubes.

Which liquid expands most with the heat?

Remove one flask from the hot water and plunge it into cold water; watch closely any change in the height of the liquid column. Explain this behaviour.

On a sheet of squared paper draw curves to represent the expansion of each liquid, ordinates indicating increase in height of the liquid and abscissas increase in temperature.

Which curve is steeper? What does that indicate?

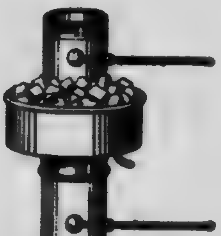

Fig. 64.—Hope's apparatus.

Exercise 50.—A study of the expansion of water near the freezing point. (Text-Book, § 264.)

Apparatus:—As the temperature of a liquid falls it usually contracts, and of course becomes heavier; but water, as it approaches the freezing point, behaves in a peculiar way. This can be studied by means of Hope's apparatus (Fig. 64.) It consists of a cylindrical glass or metal vessel surrounded at about half its height by an annular trough, and having two thermometers inserted through holes in

the sides, one at the top, the other at the bottom. To perform the experiment requires 40 or 50 minutes.

Fill the cylinder with water at a temperature of 8 or 10° C., and in the trough put a mixture of snow (or pounded ice) and salt. Then observe every minute, or half-minute, the readings on the two thermometers. It is well to surround the apparatus with some non-conducting material such as felt or cotton wool.

Enter your observations thus:—

Time.											
Upper Therm.											
Lower Therm.											

Draw curves to represent the variation in the temperatures, with the time ordinates representing temperatures and abscissas representing times.

Why does the lower thermometer fall first? At what temperature has water its maximum density? Explain the great importance of this fact in nature.

Exercise 51.—Find the coefficient of expansion of a gas, Charles' Law (first method). (TEXT-BOOK, §§ 265, 266.) *(An alternative method is given in the next Exercise.)*

APPARATUS:—Regnault's apparatus (TEXT-BOOK, Fig. 273) may be used, but that shown in Fig. 65 is simpler. A fine glass tube *AB*

FIG. 65.—Apparatus for measuring the coefficient of expansion of air.

about a metre long, closed at the end *A* contains *dry* air and a thread of mercury *m*, about 2 cm. long, which serves to enclose the air. This is put inside a larger tube, passing through a cork *D* at one end, also being held in position by a cork *E* which is pierced with holes. A thermometer *T* is bound to the fine tube.

Rest the tube CD in a horizontal position on two V-shaped blocks of wood. Introduce ice-water into the large tube through the tube F in the cork C, and let it escape at G. Keep a steady stream flowing through for some time, the fine tube being completely surrounded by the water. Tap the tube sharply to overcome the sticking of the mercury to the tube. By means of a metre rod placed alongside the larger tube, measure the distance from the closed end of the fine tube to the nearest end of the mercury thread. Assuming the bore of the tube to be uniform, this length will represent the volume of the imprisoned air. Observe the temperature; it will be near to 0° C.

Next, connect F to a boiler (see Fig. 59), and pass steam freely through CD for some minutes. When the thermometer shows a steady temperature, tap the tube again, and read the position of the index, and also the temperature again.

Let v_1, t_1 be the volume and the temperature at first, and v_2, t_2 those quantities at last. Then an approximate way to calculate the coefficient of expansion is as follows:—

Increase in volume	=	$v_2 - v_1$,
" " temperature	=	$t_2 - t_1$,
Hence, increase of volume v_1 for 1°	=	$\dfrac{v_2 - v_1}{t_2 - t_1}$
and " " " 1 " 1°	=	$\dfrac{v_2 - v_1}{v_1(t_2 - t_1)}$.

This may be taken as a, the coefficient of expansion. Strictly, however, we should start with the volume at 0° C. Let the volume at 0° C. be v_0. Then a strictly accurate calculation may be made thus:—

$$v_1 = v_0 (1 + at_1),$$
$$v_2 = v_0 (1 + at_2);$$

Dividing, $$\frac{v_1}{v_2} = \frac{1 + at_1}{1 + at_2} \text{ or } (1 + at_2)\, v_1 = (1 + at_1)\, v_2,$$

and inserting in this equation the values of t_1, t_2, v_1, v_2, which we have found we can find the value of a.

The first method of calculating will be amply accurate for our purpose, however, since there is less error in using it than is introduced in measuring the volumes of the gas.

The air experimented upon should be *dry*; the presence of moisture makes the expansion too great.

Exercise 52.—Find the coefficient of expansion of a gas, Charles' Law (second method). (TEXT-BOOK, §§ 265-268.) (*Alternative method to Exercise 51.*)

APPARATUS:—A long narrow tin vessel has an opening at one end for a cork, through which a capillary tube AB (Fig. 66), a metre or

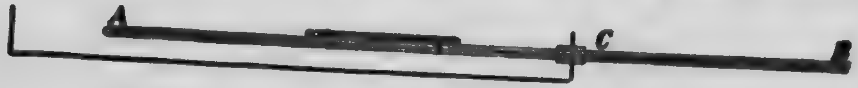

FIG. 66.—Apparatus for finding the coefficient of expansion of air.

more in length, is passed. This tube is closed at A and in it is a column of mercury 15 or 20 cm. long. The tube is surrounded by water in the vessel which can be heated by gas or spirit lamps, and a thermometer bound to the tube indicates its temperature.

First, measure the total length of the bore of the tube AB. It is evident that we can find the length of the air column AC by subtracting the distance CB from the distance AB, and CB can be measured directly.

Now take the length of the air column at different temperatures. Begin by filling the tin vessel with melting snow or melting ice, and allow it to stand for a few minutes until the air has certainly taken the temperature of the liquid about it. Then apply heat until the temperature has risen a few degrees. In taking the temperature the source of heat should be removed and the water stirred about the tube for some minutes. In order to find the length of the air column, push the tube through the cork until the end C of the mercury column can be just seen. Then measure the length CB and subtract it from the total length AB.

Tabulate results as follows:—

Temperature Centigrade.	Temperature Absolute.	Length of Air Column.	Abs. Temp. ÷ Length of Air Column.

What relation do you find between the volume and the absolute temperature?

Exercise 53.—Study the method of mixtures, and find the water equivalent of a calorimeter. (Text-Book, §§ 269-272.)

The method of mixtures. The amount of heat required to raise the temperature of 1 gram of water 1° C. is called a *calorie.* If on applying heat to 500 grams of water its temperature rises 10°, we say that the water has received $500 \times 10 = 5000$ calories of heat; and if the temperature falls 8° the water gives up $500 \times 8 = 4000$ calories of heat. Thus a calorie is taken as a unit of heat, just as a centimetre is taken as a unit of length, or a gram as a unit of mass.

Place a beaker on one pan of a balance and add shot or other small objects to the other pan until the beaker is counterpoised. Then add 300 grams more, and pour water in the beaker until equilibrium is again obtained. Have the temperature of this water 8 or 10 degrees lower than that of the room. Pour this in another beaker. Then replace the beaker on the balance and pour in 500 grams of water which is at a temperature 4 or 5 degrees above that of the room. (For this experiment, instead of weighing the water it may be measured in a graduate, assuming that 1 c.c. = 1 gram.)

Now take a third beaker, large enough to hold all the water which has been weighed out. Stir the cooler water well and take its temperature; do the same for the warmer water. Then pour the water from the two beakers into the third

one, stir it well and take the temperature. It would be well to have two thermometers, one for each beaker, so that there would be no change in one temperature while the other was being taken, but if no time is wasted this change can be neglected.

Calculate now how many calories of heat have been gained by the colder water, and how many lost by the warmer. It is evident that these should be equal.

Why was the temperature of one chosen above that of the room and that of the other below it?

Water equivalent. In performing this experiment we have made no allowance for any heat received or given up by the vessel in which the mixture is made; indeed, the circumstances were chosen so that this might be as small as possible. In most cases, however, this effect cannot be neglected and we wish to see how to allow for it.

Glass vessels are not the best to use in experiments involving the method of mixtures. They are easily broken and, besides, they are slow in taking the temperature of the water which they hold. The best vessels for our purpose are of polished metal (nickel-plated brass is very good), and it is well to have the vessel containing the water within a larger one which shields it from outside radiation. Also be careful not to communicate heat by the hand. The vessel (or vessels) in which our experiment is made is termed a *calorimeter.* A good form of calorimeter is shown in Fig. 67. Here a polished vessel A rests on a wooden block within a larger vessel B, and the temperature can be taken by a thermometer inserted through a hole in the top.

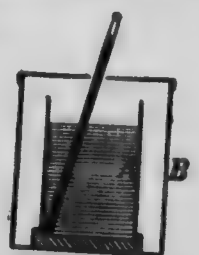

FIG. 67.—A calorimeter.

Weigh the vessel A; let its weight be w_1 grams. Pour in water 7 or 8 degrees lower than the temperature of the room until it is about half-full, and weigh again. Let it be w_2 grams. Then

the weight of the water is $w_2 - w_1$ grams. Now place it in the outer vessel B, and after stirring well take its temperature. Let it be t_1.

Have water heated to about 20 centigrade degrees above the room temperature. Take its temperature t_3 and then pour into A enough to about three-fourths fill it. Stir well (with the thermometer or with a special stirrer) and take the temperature. Let it be t_2. Finally weigh the vessel A and its contents again. Let its weight be w_3 grams. It is evident that the amount of warm water poured in was $w_3 - w_2$ grams.

In this case $w_3 - w_2$ grams of warm water falls in temperature from t_3 to t_2, and the heat it gives up raises the temperature of $w_2 - w_1$, grams of cold water from t_1 to t_2; also the temperature of the vessel A of the calorimeter from t_1 to t_2.

Let e grams of water be equivalent to the calorimeter, that is, it takes the same amount of heat to raise e grams of water through 1° as it does to raise the temperature of the calorimeter through 1°. In other words, instead of counting the $w_2 - w_1$ grams of cold water and the calorimeter separately we can take the two together as the same as $w_2 - w_1 + e$ grams of water.

Calculate thus:—

Heat given out by warm water $= (w_3 - w_2)(t_3 - t_2)$ calories,
Heat received by cold water $= (w_2 - w_1)(t_2 - t_1)$ calories,
Heat received by calorimeter $= e\,(t_2 - t_1)$ calories,
or heat received by cold water and calorimeter $= (w_2 - w_1 + e)(t_2 - t_1)$ calories;

$$\text{Hence } (w_2 - w_1 + e)(t_2 - t_1) = (w_3 - w_2)(t_3 - t_2),$$

$$\text{and } e = \frac{(w_3 - w_2)(t_3 - t_2) - (w_2 - w_1)(t_2 - t_1)}{(t_2 - t_1)} \text{ grams.}$$

A numerical example will illustrate this:—

Observations:—

Weight of calorimeter . . .	233.3 grams.
Weight of calorimeter + cold water . .	653.7 "
Temperature of calorimeter and cold water	12.8° C.

Observations :—(*Continued*).

Temperature of warm water - - -	42.0° C.
Final temperature of mixture - - -	23.2 "
Weight of calorimeter + cold + warm water	898.7 grams.

From which,

Weight of cold water - - - - -	420.4 "
Weight of warm water - - - - -	245.0 "

Calculation :—

Let calorimeter be equivalent to e grams of water.

Heat received by calorimeter and cold water

$$= (420.4 + e)(23.2 - 12.8) \text{ calories.}$$

Heat given up by warm water

$$= 245 (42.0 - 23.2) \text{ calories.}$$

These quantities are equal,

$$(420.4 + e)(23.2 - 12.8) = 245 (42.0 - 23.2),$$

or,

$$10.4 (420 + e) = 245 \times 18.8,$$

and

$$e = 22.5 \text{ grams (approx.).}$$

In this case the calorimeter was of brass, and taking its specific heat as 0.094 we compute the approximate value of the water equivalent to be

$$233.3 \times 0.094 = 21.9 \text{ grams.}$$

Exercise 54.—Find the specific heat of copper. (TEXT-BOOK, § 272.)

To raise the temperature of 100 grams of water through 10 cent. degrees requires 100 calories of heat; while it is found by experiment that to raise 100 grams of lead through 1° requires only 3 calories. The fraction $\frac{3}{100}$, that is, the ratio of the quantity of heat required to raise the temperature of a mass of lead 1° to the quantity required to raise an equal mass of water 1° is called the *specific heat of the lead.* It is evident that while to raise 1 gram of water 1° requires 1 calorie, to raise 1 gram of lead 1° requires $\frac{3}{100}$ calorie; and so we can define the *specific heat of a substance* as the *quantity of heat required to raise 1 gram of the substance 1 cent. degree*, or as *the thermal capacity of 1 gram of the substance.*

Usually a small cylindrical dipper with a handle on it is supplied with the boiler shown in Fig. 59. On screwing the top off, this fits in the opening (Fig. 68). The apparatus shown in Fig. 69 may also be used.

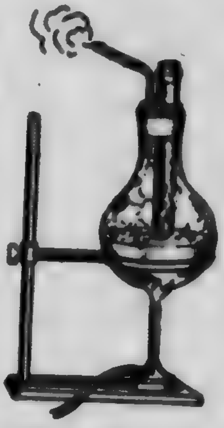

FIG. 69.—Determination of specific heat of a solid.

Take about 600 or 700 grams of short pieces of copper wire, tie them together with strong thread, leaving a few inches free for lifting the bundle. Weigh the copper; let the weight be w_1 grams. Start the boiler going, lower the copper into the dipper and set the dipper in the boiler. Cover it with a sheet of cardboard, and push a thermometer through a hole in the cardboard so that the bulb may be close to the copper.

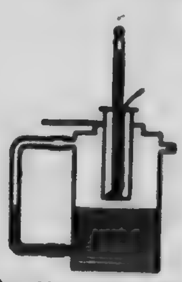

FIG. 68.—Apparatus for finding the specific heat of a solid.

Weigh out in the calorimeter about 150 grams of water which has been cooled to a temperature 7 or 8 degrees below that of the room. Let the weight be w_2 grams.

After the temperature of the copper has ceased rising record it. Let it be t_1. Withdraw the thermometer, and after letting it cool, put it in the water in the calorimeter, and after stirring it about record the temperature shown. Let it be t_2.

Then take the thermometer out of the water, and removing the copper from the dipper drop it quickly into the water. Move the copper about until the temperature of the water ceases to rise, and then read its temperature. Let it be t_3.

Let s = specific heat of the copper,
and e = water equivalent of the calorimeter.
Then heat given out by the copper $= w_1 s (t_1 - t_3)$ calories.
Heat received by water and calorimeter $=(w_2+e)(t_3-t_2)$ calories,
$\therefore\ w_1 s (t_1 - t_3) = (w_2 + e)(t_3 - t_2)$,
from which s can at once be determined.

Instead of tying the copper pieces in a bundle they may be left loose and then simply dumped into the calorimeter.

If the water equivalent of the calorimeter is not known it may be taken as equal to the mass of the calorimeter (*i.e.*, the inner vessel which changes its temperature) multiplied by its specific heat.

Numerical example (specific heat of iron).

Observations :—

Weight of calorimeter	104.2 grams.
Weight of calorimeter + cold water . .	470.8 "
Initial temperature of water . . .	14° C.
Weight of iron	340.4 grams.
Temperature of iron	100° C.
Final temperature of water and iron .	22° C.

From which,

Weight of cold water	366.6 grams.
Water equivalent of the brass calorimeter, taking specific heat of brass as 0.094 is $104.2 \times 0.094 =$	9.8 grams.

Calculation :—

Heat received by calorimeter and water

$$= (366.6 + 9.8) \times (22 - 14) \text{ calories.}$$

Heat given out by the iron

$$= 340.4 \times (100 - 22) \times s \text{ calories,}$$

where s is the specific heat of iron.

Hence $340.4 \times (100 - 22) \times s = (366.6 + 9.8) \times (22 - 14)$,

or $\quad 26551.2\, s = 3011.2$,

or $\quad s = 0.113$.

Exercise 55.—Find the melting-point of paraffin or of beeswax. (TEXT-BOOK, §§ 273-277.)

Heat some small glass tubing in a flame and draw it out into a fine tube. Cut off a piece a few inches long, and dip the fine end in melted paraffin, and then fuse the end of the tube in the flame. (If the tube is large enough small pieces of the wax may be dropped into it, or if the tube is very fine it may be held in the melted wax and then used without being fused at all.)

Bind the tube to a thermometer so that the wax is near the bulb, and then hold it in a beaker of water to which heat is applied gradually. Keep the water well stirred, and note carefully the temperature when the wax becomes transparent and runs down the tube.

Next, remove the heat and let the water cool, and observe the temperature when the wax becomes opaque again. Take the mean of these two temperatures as the melting point.

Exercise 56.—Study the effect of salt upon the boiling point of water.

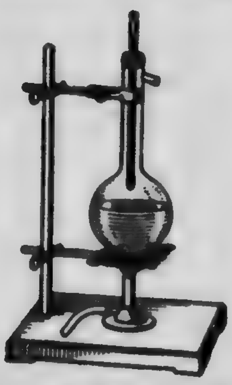

Fig. 70.—Finding the boiling point of a salt solution.

APPARATUS:—That shown in Fig. 70. The flask should have a capacity of about 300 c.c., and be about half-full of water. If an ordinary flask is used two holes should be bored through the cork, one for the thermometer, the other for a glass tube.

Heat the flask carefully, protecting it from the flame by wire gauze, until the water boils. First, have the thermometer bulb in the steam above the water. What temperature does it show? Let it boil for a few minutes; does the temperature change? Then push the bulb down into the water. What is the temperature? Does it remain steady? Next, add about 10 grams of salt, and boil. Place the bulb in the solution, and note the temperature. Then remove the thermometer, wipe the bulb, and replace it so that the bulb is in the steam above the solution. Again, note the temperature. Repeat these observations, using 20 grams of salt in the solution.

State in your note-book what is the effect on the boiling point of water of adding common salt to it, and also what is the effect on the steam rising from it.

Exercise 57.—Find the lowest temperature obtainable with a mixture of snow and salt. (TEXT-BOOK, § 280.)

Mix well together the snow (or broken ice) and salt, and insert in it a thermometer which reads to about $-20°$ C. Use

varying quantities of salt, and see how low a temperature is obtainable.

Exercise 58.—Determine the cooling curve through change of state (solidification). (TEXT-BOOK, §§ 273, 274.)

(*1*) *For paraffin.* Heat some paraffin contained in a test-tube to about 60° C.; place a thermometer in it and regularly observe it at intervals of 1 minute as the wax cools in the air. The paraffin should be heated by holding the tube in water heated by a gas or other flame.

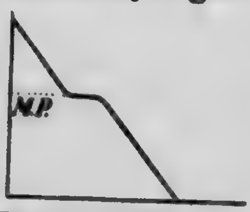

FIG. 71.—A cooling curve.

Plot a curve (Fig. 71), having temperatures for ordinates and time for abscissas.

(*2*) *For water.* A similar experiment can be tried with water, a suitable arrangement being shown in Fig. 72. The water, which should be distilled, is held in a large test-tube, and the thermometer is in a thin-walled test-tube containing mercury and just large enough to admit the thermometer.

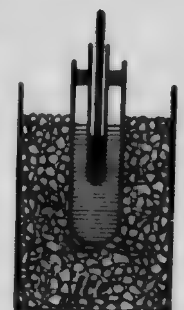
FIG. 72.—Apparatus for obtaining cooling curve for water.

The large tube is packed in a freezing mixture of snow and salt. Read the temperature every half-minute, and plot a curve as above.

Exercise 59.—Find the heat of fusion of ice. (TEXT-BOOK, §§ 277, 278.)

The heat of fusion of ice, or the latent heat of water, is the quantity of heat required to convert one gram of ice at 0° C. into one gram of water at 0° C.

Weigh the calorimeter. Half-fill it with water at a temperature of 30 or 35° C. Weigh again, and thus obtain the mass of the water. Let it be w_1 grams. Take some pieces of ice, having a mass about one-sixth that of the water. Stir the water well and take its temperature. Let it be t_1. Dry the ice with a towel or a flannel cloth, and quickly drop it into the

water. Stir (by means of the thermometer or other stirrer), and observe the lowest temperature reached by the water. Let it be t_2. Again weigh the calorimeter and its contents, and by subtraction find the weight of the ice added. Let it be w_2.

Let x = heat of fusion of ice. To change the ice into water, without raising its temperature, requires $w_1 x$ calories of heat; and to raise the temperature of the water which comes from the ice from 0° C. to t_2 requires $w_1 t_2$ calories. The heat required comes from the water and the calorimeter cooling down from $t_1°$ to $t_2°$. Take e as the water equivalent of the calorimeter, so that the calorimeter and the water in it are together equal to $w_1 + e$ grams of water.

$$\text{Heat given up} = (w_1 + e)(t_1 - t_2) \text{ calories},$$

$$\text{Heat received} = w_1 x + w_1 t_2 \text{ calories},$$

$$\text{Hence } w_1 x + w_1 t_2 = (w_1 + e)(t_1 - t_2),$$

$$\text{or } x = \frac{(w_1 + e)(t_1 - t_2)}{w_1} - t_2.$$

Exercise 60.—Find the heat of vaporization of water. (TEXT-BOOK, §§ 289, 290.)

APPARATUS:—That shown in Fig. 73 is very convenient. In the absence of the boiler there seen, a tin can or a glass flask may be used.

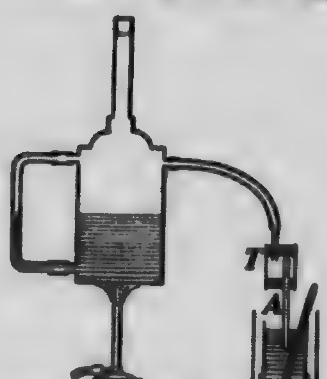

FIG. 73.—Finding the latent heat of steam. The trap T is made from a glass tube about 2 inches long and 1 inch diameter, with a glass tube through a cork in each end.

The heat of vaporization of water, or the latent heat of steam, is the quantity of heat required to convert one gram of water at its boiling point into steam at the same temperature; or the quantity of heat given out by one gram of steam when it changes to water at the same temperature.

Weigh the calorimeter. Fill it $\frac{2}{3}$ full of water and then weigh it with much care. Let the weight of the water be w_1 grams. This water should be at a temperature of about 5° C. Let it be $t_1°$.

Now have steam coming freely from the boiler and passing by means of a rubber tube (about which a cloth should be wrapped) into a trap T. Introduce the delivery tube A into the calorimeter and thrust it 2 or 3 cm. below the surface of the water, and keep up a vigorous current of steam. This will be shown by a noisy and incessant collapse of bubbles as they come in contact with the cold water.

Keep stirring the water and when its temperature has risen to about 35° C. quickly remove the delivery tube. Stir the water thoroughly and quickly and take its temperature; let it be t_2. Then with no unnecessary delay weigh the calorimeter and its contents. This weighing should also be made with much care. Subtract the last weight from this one and thus obtain the weight of the steam which has entered the water. Let w_2 be the weight of the steam.

We can now obtain the latent heat of steam as follows:—

Let w_1 = weight of water at first,
t_1 = its temperature,
e = water equivalent of the calorimeter,
w_2 = weight of steam introduced (assumed at 100° C.),
$t_2°$ = final temperature,
x = latent heat of steam (*i.e.*, the number of calories of heat given up by 1 gram of steam when it changes to water at the same temperature).

Heat given out by steam on changing to water = xw_2 calories.
" " " by the water from the steam = $w_2(100 - t_2)$ calories.
Heat received by water and calorimeter = $(w_1 + e)(t_2 - t_1)$ calories.

$$\text{Hence } xw_2 + w_2(100 - t_2) = (w_1 + e)(t_2 - t_1)$$

$$\text{and } x = \frac{(w_1 + e)(t_2 - t_1)}{w_2} - (100 - t_2).$$

The trap is used to catch any water condensed from the steam in the pipes and prevent it from trickling into the calorimeter. It can be dispensed with entirely. In

Fig. 74 is shown a simple form of the apparatus, in which no trap is used.

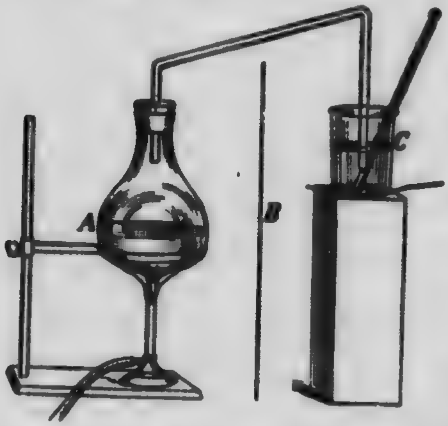

FIG. 74.—Simple apparatus for finding heat of vaporization. *B* is a screen to protect the calorimeter *C* from the source of heat. Water condensed in the delivery tube runs back into the flask.

As the latent heat is high the quantity of steam used is small and care must be taken in the weighings. A small error in the weight of the steam will make a considerable error in the result.

Exercise 61.—Find the dew-point. (TEXT-BOOK, §§ 295, 296.)

APPARATUS:—That shown in TEXT-BOOK, Fig. 289, or simply a polished thin metal cup.

We wish to find the temperature at which the moisture which is present in the air condenses.

Half-fill with tap water a thin polished metal cup—one of aluminium or of nickel-plated brass will answer well. Continue dropping small pieces of ice in, stirring well all the time, until dew is seen to form on the outside. Then take the temperature of the water with a thermometer which should read to $\frac{1}{5}$ or $\frac{1}{10}$ of a degree. This temperature is probably a little below the dew-point.

Now make small additions of water at the temperature of the room until the mist begins to disappear, and then take the temperature again. This will probably be a little higher than the dew-point. Take the mean of the two temperatures as the dew-point.

Repeat the experiment several times. After one or two trials the temperature found going down will be pretty close to that found going up.

Be careful not to breathe upon the outside of the vessel or to hold any damp object near it while looking for the mist to

form. A sheet of glass stood in front of the apparatus will protect it.

If a thick layer of moisture forms upon the vessel before the reverse process is begun, it should be wiped off.

Record in your note-book the state of the weather and the temperature out-of-doors.

Exercise 62.—Find the relative conductivities of some metals. (TEXT-BOOK, §§ 310, 311.)

APPARATUS:—The apparatus, devised by Edser, is illustrated in Fig. 75. *A* is a vessel, which may be made from a piece of brass tubing 10 cm. in diameter and 20 cm. long, the bottom being closed by a brass disc. A number of holes are bored in this to receive rods (about 2.5 mm. in diameter and 15 cm. long) soldered in position perpendicular to the bottom. Each rod is provided with a small index made from copper wire about 0.8 mm. in diameter (No. 20 wire), bent in the form shown enlarged at *B*. The indexes are made by winding the wire on rods slightly larger than the rods in the bottom of the vessel.

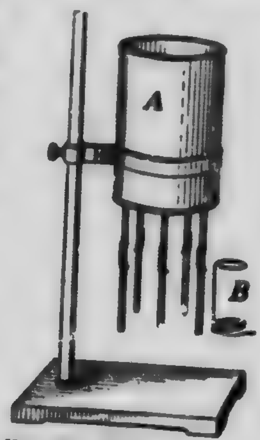

FIG. 75.—Edser's apparatus for finding relative conducting powers of metal rods.

To begin with, the vessel *A* is inverted, an index is slipped on each rod, and a very small amount of paraffin wax is melted around the rings. When the vessel is turned right-side-up, as shown in the figure, the solid wax holds the indexes in position.

Now pour boiling water into the vessel. As the rods get heated the wax is melted and the indexes slip down carrying the wax before them, and when the temperatures of the rods have acquired steady values the indexes will have descended to points on the various rods where the wax just solidifies, and which therefore possess equal temperatures.

Now measure the distances from the bottom of the vessel to the projecting point on each index. It has been proved (in works on the theory of conduction of heat) that the conducting powers are proportional to the squares of these distances.

Find the squares of the distances measured, and taking the conductivity of copper as 100, compute the conductivities of the other rods.

Perform the experiment several times: it does not take long to do it.

If desired, the rods may be electroplated. This does not measurably alter their conductivities and it eliminates any differences in the nature of the surfaces.

Exercise 63.—Determine (approximately) the mechanical equivalent of heat; i.e., find the amount of energy which is equivalent to unit quantity of heat. (TEXT-BOOK, §§ 302, 303.)

APPARATUS:—A stout card-board tube about 1 m. long and 5 cm. in diameter, about 500 gm. of lead shot 1.5 mm. in diameter, and a delicate thermometer.

Fit each end of the tube with a sound cork, and insert one cork. Place the thermometer in the shot, which may conveniently be held in a card-board box, and read the temperature accurately. Let it be t_1° C.

Now pour the shot into the tube, held in an almost horizontal position, and then, holding the tube upright, measure the distance from the upper surface of the shot to the bottom of the upper cork when it is inserted in the tube. Let this distance be h cm.

Next take hold of the middle of the tube and quickly invert it so that the other end comes uppermost. The shot will drop to the bottom. Repeat this 100 times, then quickly pour out the shot and take its temperature. Let it be t_2° C.

Let m grams = mass of the shot,
s = specific heat of lead.

Then mechanical work done = 100 mh gram-centimetre units,
= 100 mgh ergs.

And heat developed = $ms(t_2 - t_1)$ calories.

Hence the mechanical work equivalent to 1 calorie $= \dfrac{100\,mgh}{ms(t_2 - t_1)} = \dfrac{100\,gh}{s(t_2 - t_1)}$ ergs.

Repeat the experiment, making 150 inversions of the tube.

Part VI—Light

Exercise 64.—Study the images produced through small apertures. (Text-Book, §§ 332, 333.)

Apparatus:—The most convenient apparatus for this experiment is an ordinary camera from which the lens has been removed. In its place substitute a sheet of tin-foil in which holes of any desired size and shape may be punched. In the absence of such a camera use a box about 6 inches square and 12 inches long. Over an opening in one end fasten a piece of tin-foil, and cover the other end with thin paper, tracing cloth or ground-glass.

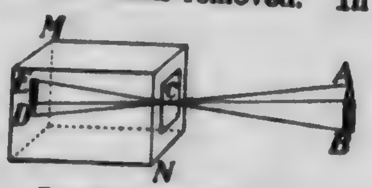

Fig. 76.—A pin-hole camera.

Place a candle or an incandescent lamp in front of the box, and pierce a hole in the tin-foil with a pin. Observe the image on the ground-glass by covering the head and the back of the camera with a dark cloth.

Note the position (erect or inverted) of the image, also how clear or sharply defined it is. Measure the height of the candle and of its image, and their distances from the pin-hole. Place the candle at different distances and measure these quantities for each distance. Arrange the results in a table, thus:—

Height of Object.	Height of Image.	Ht. of Object. / Ht. of Image.	Object from Pin-hole.	Image from Pin-hole.	Obj. from Pin-hole. / Im. from Pin-hole.

Now make a three-cornered or an oblong hole in the tin-foil. Do you notice any difference in the image? Make the first hole larger. What change in the image? Make several holes near together. What result? Now make them all into one hole, and note the result.

It is wiser to make these experiments on the effect of size and shape of aperture before the measurements referred to above are made. In this case a fresh piece of tin-foil will be required for the second part of the work.

In your note-book describe all your experiments and the results observed. Also make a sketch showing why the images are inverted; and answer the following questions:—

(*a*) On what does the brightness of an image depend?

(*b*) On what does the sharpness of definition depend?

Exercise 65.—Use of a photometer. (Text-Book, §§ 336-340.)

Apparatus:—A simple but efficient photometer can be made from two blocks of paraffin wax, 6 or 7 mm. thick and about 2.5 cm. square. They should be cut from the same slab of paraffin, carefully made of the same thickness and then placed together with a sheet of tin-foil between them (*a*, Fig. 77). They may be simply set on a

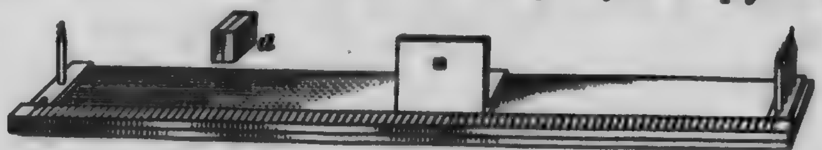

Fig. 77.—A paraffin-block photometer.

stand, or may be placed at the back of a piece of wood or metal with a hole about 1 cm. square in it, the blocks being so arranged that an equal amount of each is seen through the aperture. This, as well as the board on which it moves, should be painted black, and the entire photometer should be used in a darkened room and screened off from other lights. If this photometer cannot be obtained, use a Bunsen or a Rumford photometer.

I. Verify the law of inverse squares. At one end of the blackened board place one candle, and at the other (1 m. or more away) place four candles. (Fig. 77.) Have the candles

all burning equally well. Now move the photometer back and forth until the two portions of paraffin are equally bright. If the two lights are of the same colour, as they are in this case, the tin-foil line of separation will disappear. If the colours are not identical, one must judge when the two portions are equally bright. This can be done quite accurately after a little practice. Make 2 or 3 adjustments of the photometer, measuring the distance from the lights to the photometer each time. Let the distance from the single candle to the photometer be d_1, that of the four candles be d_2. Take the average of your values of d_1 and d_2.

Then change the distance between the lights and, adjusting the photometer as before, obtain new values for d_1 and d_2 and take the average again.

Repeat this with another distance between the lights. Tabulate your results thus:—

From 1 Candle to Photometer $= d_1$.	From 4 Candles to Photometer $= d_2$.	$\left(\frac{1}{d_1}\right)^2 \div \left(\frac{1}{d_2}\right)^2 = \left(\frac{d_2}{d_1}\right)^2$.

These experiments may be further extended by using 9 candles in place of the 4, in which case the ratio $\left(\frac{d_2}{d_1}\right)^2$ should $= 9$.

II. Determine whether the light sent out by a flat flame when seen broadside is the same as that sent out when it is seen edge-on.

Arrange two lights (oil lamps or flat gas flames) at the two ends of the photometer board, and let the flat face of each be

turned towards the centre. Let the strengths of the left and right hand lights be L_1, R respectively. Adjust the photometer between them, and measure the distance to each light. Repeat this adjustment two or three times and take the average of the results. Let the distances be d_1, d_2. Then from the law of inverse squares $\frac{L_1}{R} = \left(\frac{d_1}{d_2}\right)^2$.

Try several distances between the lamps, adjusting the photometer for each distance at least 3 times. Tabulate your results thus :—

d_1.	d_2.	d_1^2/d_2^2.

Mean .... $= \frac{L_1}{R}$.

Next turn the left lamp until its edge is turned towards the centre. Let its strength now be L_2. Proceed precisely as before and find the value of $\frac{L_2}{R}$.

Finally, to compare L_1 with L_2, divide the values found for $\frac{L_1}{R}$ and $\frac{L_2}{R}$. Thus $\frac{L_1}{R} \div \frac{L_2}{R} = \frac{L_1}{L_2}$. This gives the number of times the lamp with broadside flame is greater than with flame edge-on.

Various other experiments can be performed with the photometer, such as the comparison of an electric lamp or oil flame with a candle.

Exercise 68.—Establish the laws of reflection. (Text-Book, § 346.)

Apparatus :—The optical disc.

With this apparatus verify the laws of reflection, according to instructions accompanying the apparatus.

Exercise 67.—Establish the law of reflection. (TEXT-BOOK, § 346.)

APPARATUS:—As a mirror use a strip of unsilvered plate-glass about 1 inch wide and 3 inches long. A microscope slide answers well. Blacken one face of the glass and then attach it to a rectangular block of wood, with the blackened face against the wood. This may be done with two bent-wire clips (*a*, Fig. 78). The reason for not using a piece of ordinary mirror is that it is silvered on the back, while it is best to have reflection from the front surface.

Draw a straight pencil-mark AB (Fig. 78) across a sheet of white paper, and lay the block on it so that the front face (which is the reflecting face) of the mirror is along this line. The face of the mirror should be vertical; when such is the case the paper which is before the mirror and its reflection in the mirror appear to be one continuous plane.

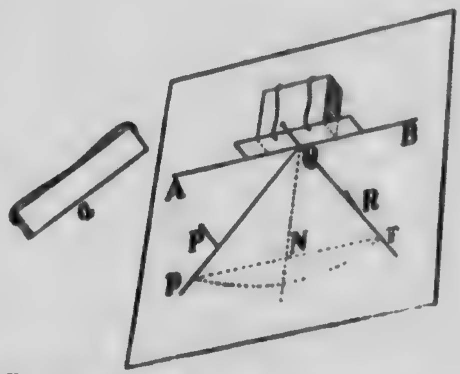

FIG. 78.—Arrangement for testing the law of reflection.

Stick a pin Q through the paper close against the surface of the mirror and another pin P at some distance from Q in an oblique direction. Now look with one eye along the line PQ, so that the pin Q is hidden behind the pin P; and without moving the head stick another pin R in such a position that it also appears in the line PQ. In the same way, if one looks along the line RQ the three pins will appear to be in a straight line.

Remove the mirror and the pins, and with a fine pencil draw the lines PQ, RQ. Also, with a set-square or with compasses, draw the perpendicular QN to AB. It is evident from our experimenting that if PQN is the angle of incidence, RQN is the angle of reflection. With a protractor measure

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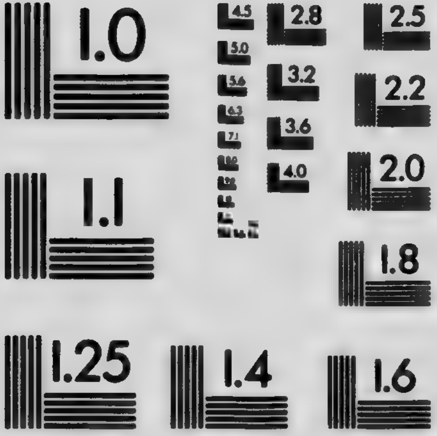

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each of these angles. If a protractor is not at hand, with centre Q describe a circle cutting PQ and RQ in p and r respectively. Join pr and measure pN, rN with a millimetre scale. Repeat with another position of P.

In your note-book copy the figure on a reduced scale and mark the angles and lengths on it.

Exercise 68.—Show that when a mirror is rotated through an angle the reflected ray is rotated through twice that angle.

Apparatus.—The same as in the last Exercise. The optical disc may also be used.

First, obtain the position of R, the image of P in the plane mirror. Then turn the mirror about Q through an angle of about 5° and draw a line along its face to show its new position. Let this be $A'B'$. Also find the new position of R. Let it be R'. Then QR' is the direction of the reflected ray. With a protractor measure the angle between AB and $A'B'$, and also between QR and QR'.

Continue rotating the mirror through small angles and determining the direction of the reflected ray, and measure the angles in each case between the new position of the mirror and the first position, also between the new direction of the reflected ray and the first direction.

Arrange your results in a table thus:—

Angle Turned Through by Mirror.	Angle Turned Through by Reflected Ray.

Exercise 69.—Measure the angle of a prism. (TEXT-BOOK, § 346.)

APPARATUS:—Prism, protractor, ruler and pins.

Place the prism on a sheet of paper, and if possible draw its trace ABC (Fig. 79). Then by means of a protractor the angle BAC can at once be measured.

Obtain the angle also in the following way:—Stick a pin P into the table at a distance of about 1 foot from the edge of the prism, and in such a position that the line PA is approximately equally inclined to AB and AC.

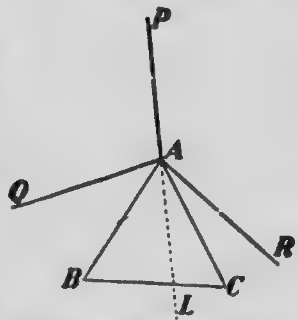

FIG. 79.—How to measure the angle of a prism.

Look at the face AB and obtain an image of the pin P in it, placing the eye in such a position that the image coincides as nearly as possible with the edge A. Stick a pin Q in the line joining the eye to A. Thus on looking along the line QA the pin P also appears in that line.

Next, stick a pin R in such a way that looking from R to A the pin P appears in the same line.

Remove the prism and the pins, and draw the lines QA, RA. Then the angle QAR is twice the angle of the prism. Measure it with a protractor and take half of it.

This method is no more accurate than the direct method, but sometimes the direct method cannot be used. The most accurate method of all,—by means of a spectrometer,—is identical in principle with the latter.

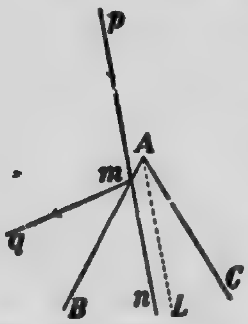

FIG. 80.—Enlarged diagram to show the reflection at the edge of the prism.

We can easily prove that the angle QAR is double the angle BAC. Consider a much enlarged portion of the figure in the neighbourhood of A. Let pm (Fig. 80) be a ray (coming from P) incident on the face at m and let qm be the reflected ray (going to Q). Produce pm to n, and draw AL parallel to mn. Then since the incident and reflected rays

make equal angles with the normal to the surface they also make equal angles with the surface. Hence the angle pmA = the angle qmB. But from the figure it is seen that the angle pmA = the angle Bmn, which = BAL. Hence the reflected ray qm makes with the face BA an angle equal to BAL.

Similarly the ray reflected from the face CA makes with that face an angle equal to CAL. Hence the angle between the two reflected rays is double the angle BAC.

Exercise 70.—Study the images in a plane mirror. (Text-Book, §§ 349, 350.)

Apparatus :—A plane mirror and a penknife.

Stand the mirror on a table and place a penknife, with the small blade opened 90°, upright before the mirror. Where does the image appear to be? Turn the open blade so as to point towards the mirror. In what direction does the image point? Hold the right hand before the mirror. Which hand doesn't appear to be in the image? What name is given to this apparent changing of sides?

Open both blades out fully and lay the knife on the table with the point of one blade touching the mirror. Where does the image appear to be? Continually increase the angle made with the mirror by the knife and note the image in each case.

Lay the knife on the table 3 or 4 inches from the mirror. Note the position of the image. Turn the mirror through about 30°, and note the position of the image again.

Make drawings to locate the position of the image in all the above cases.

Exercise 71.—Study the images in parallel mirrors. (Text-Book, § 351.)

Place two mirrors vertically on a table parallel with, and facing each other, and place a lighted candle between them.

Now look obliquely into one mirror just over the edge of the other.

How do you account for the large number of images seen? What limit is there to the number formed? Why do they appear at equal distances in the same straight line? To answer this question draw the rays by which any three successive images are seen.

Exercise 72.—Study the images in a thick mirror.

Place a lighted candle in front of a thick plate-glass mirror; locate three images, and make a drawing to explain their position and relative brightness.

Can a thick mirror be considered a particular case of parallel mirrors? Explain.

Exercise 73.—Study the images in inclined mirrors. (Text-Book, §§ 352, 353.)

Place upright on a table two plane mirrors meeting at an angle of 90°. The angle can be determined by having the mirrors rest upon a sheet of paper on which is drawn a circle graduated in degrees, the line in which the mirrors meet being at the centre of the circle.

Stand a candle between the mirrors. How many images can be seen? Make a drawing to locate the images, and also show on it how the light passes from the candle to the eye.

Repeat the experiment with mirrors inclined at 60°, 45°, 72° and 40°.

Exercise 74.—Study the images produced by concave and convex mirrors. (Text-Book, §§ 354-363.)

Apparatus:—For this experiment we require concave and convex mirrors, a screen of ground-glass or white card-board, a candle, a gas-flame or an incandescent lamp. They should all be mounted at the same height, and the source of light, the *object*, should always be placed directly in front of the mirror. The radius of curvature of the mirrors should not be too small, 20 to 50 cm. preferably.

I. Concave Mirror. Hold the candle about 2 m. from the mirror, and move the screen so that the image is sharply

shown on its edge. Is it erect or inverted? Enlarged or diminished? Is it real or virtual? Then slowly bring the flame towards the mirror, continually moving the screen so that the image is always distinctly formed on it. The screen and object gradually approach and then come together. The object and image are now at the *centre of curvature.* Note the characteristics of the image (erect or inverted, enlarged or diminished, real or virtual). Let the centre of curvature be denoted by C, and let A be the *vertex*, *i.e.*, the middle point of the reflecting surface of the mirror. Half-way between C and A is F, the *principal focus.*

Move the object from C towards F, and follow the image with the screen. At last the screen has to be taken to the opposite side of the room—the image is formed on the wall. The object may be taken as at the principal focus F.

Then move the object nearer the mirror still. Where is the image now? (Look in the mirror.) Note its characteristics.

Next perform these operations in the reverse order, *i.e.*, starting as near as possible to A, move the object outward passing through F and C, until it is as far away as possible, and obtaining on the screen a distinct image of it in its various positions.

Tabulate your observations as follows:—

CONCAVE MIRROR

Position of Object.	Position of Image.	Characteristics of Image.*
At infinite distance..		
Beyond C.........		
At C..............		
Between C and F....		
Between F and A....		
At F.............		

(* Real or virtual, erect or inverted, enlarged or diminished.)

II. Convex Mirror. Investigate the convex mirror in the same way. Test for positions of the object extending from the vertex to a great distance, and note the characteristics of the image for various distances.

Exercise 75.—Find the radius of curvature of a concave spherical mirror. (Text-Book, § 357.)

Apparatus:—Mounted concave mirror, screen, mounted knitting needles, lamp.

1. Hold the mirror in the sunlight so that the rays fall directly upon it, and receive the image on the edge of a white card or a narrow strip of paper held in front of the mirror. Move the screen until the image is smallest and most distinct. The distinctness of the image can often be improved by using only the central portion of the mirror. To do this, cut a round hole about 2 cm. in diameter in a piece of brown paper and place this over the mirror. Having obtained the sharpest possible image on the screen measure its distance from the vertex of the mirror. This is the focal length, which is one-half the radius of curvature.

2 If you cannot use sunlight obtain the image of a bright window as far off as possible.

3. In a piece of card-board make a hole 6 or 7 mm. in diameter, and across it stretch two black threads or pieces of fine wire (Fig. 81). They may be held in place by wax or by a label pasted over their ends. Mount the card on an upright so that the cross-threads are at the same height as the vertex of the mirror. Illuminate the threads

Fig. 81.—Finding the radius of curvature of a concave mirror.

by placing a strong lamp behind. Now move the mirror so that a distinct image of the hole falls on the card-board just beside the hole itself. When this is the case the cross-threads are at the centre of curvature of the mirror. Measure the distance from the cross-threads to the vertex; this is the radius of curvature.

4. By means of conjugate foci. If p is the distance of an object from the mirror, p' the distance of its image and r the radius of curvature, then it can be shown (see page 124) that

$$\frac{1}{p} + \frac{1}{p'} = \frac{2}{r}.$$

The distances p and p' can be measured and r then calculated.

Place two knitting needles P and Q on stands in front of the mirror (Fig. 82)—all being on an optical bench, if you have one. First, move P close up to A. Its image is seen in the mirror, virtual, erect and enlarged. Gradually draw P away and the image retreats behind the mirror, until at last it vanishes when P reaches the principal focus. Now move P farther out, *i.e.*, between the principal focus and the centre of curvature. By standing back and looking along the axis of the mirror the image, which is real, inverted and enlarged, will be seen. We wish to locate it exactly. To do so move the needle Q until it coincides with the image of P. In that case Q and P must be on an axis of the mirror; if necessary, rotate and adjust the mirror until the image of P appears with its tip just touching the tip of Q. In order to test whether Q and the image of P actually coincide, move the head from side to

FIG. 82.—Locating the image in a concave mirror by knitting needles on stands.

side. If the coincidence remains perfect in different positions of the head, it is as required. If there appears to be a motion of one relative to the other the adjustment is not perfect and Q must be moved until it is.

This method of locating the image of an object is called the *parallax method.* By parallax is meant the apparent change in the position of a body due to change in the position of the observer. In this case the image at Q seemed to change its position as the head was moved from side to side.

Having secured perfect coincidence, measure the distances of P and Q from A. These are the quantities p and p'; insert them in the formula and thus deduce the value of r.

Try at least 5 positions of P. Calculate r for each and tabulate the results. Also arrange in a table the values of r determined by all the methods described above.

Exercise 76.—Find the radius of curvature of a convex spherical mirror (first method). (TEXT-BOOK, § 357.) (*An alternative method is given in the next Exercise.*)

APPARATUS:—Convex mirror, screen with rectangular opening in it.

Make a round paper disc to cover the face of the mirror, and in it cut two slits at a measured distance apart, as in a, Fig. 83. If the mirror is 4 inches in diameter, these may be $1\frac{1}{2}$ inches apart. Hold a screen like that in b, Fig. 83 before the mirror, and let the sun's rays, or the parallel rays from a projecting lamp, pass through the hole in the screen and strike the small uncovered spots m, p of the mirror. Then nm is the incident ray, which is reflected along mL, and qp, that which is reflected along pM. There will be two bright spots at L, M, on the back surface of the screen. Move the mirror until the distance $LM = 2\ mp$.

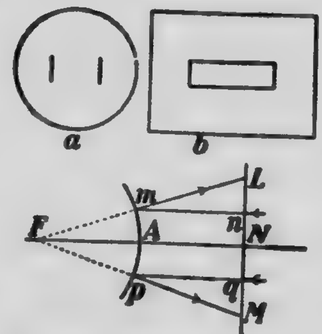

FIG. 83.—Finding the focal length of a convex mirror.

From the figure we see that LFN and Lmn are similar triangles, and if $LN = 2\,Ln$, then $FN = 2\,mn = 2\,AN$, or $FA = AN$, and hence the focal length is equal to the distance of the screen from the mirror.

A second and more accurate method is given in the next exercise.

Exercise 77.—Find the radius of curvature of a convex spherical mirror (second method). (*Alternative method to Exercise 76.*)

APPARATUS :—A convex and a plane mirror, a small needle and a knitting needle on stands. The radius of the convex mirror should be 30 cm. or more and its aperture not less than 5 cm.

FIG. 84.—Parallax method of finding the radius of curvature of a convex mirror.

Place a knitting needle P (Fig. 84) before the convex mirror A. An eye placed at E will see its image at P' behind the mirror, and we desire to locate this image accurately.

To do so place a plane mirror M in front of the lower half of the convex mirror, and before this place a small needle on a stand R. Its image will be seen behind M. Move R about until this latter image coincides with the image of P in the convex mirror. If they coincide there will be no motion of one relative to the other when the head is moved from side to side.

Then p = the distance of the object from the mirror,
$= AP$, which can be measured at once.

Also p' = the distance of the image from the mirror,
$= AP'$.

Now $P'M = RM$, and $AP' = P'M - AM = RM - AM$.

Measure RM and AM, and on subtraction obtain AP' or p'.

The formula connecting p and p' (see page 124) is

$$\frac{1}{p} + \frac{1}{p'} = \frac{2}{r}.$$

Substituting the values of p and p' in this formula we obtain the value of r. Observe, however, that p is "+" and p' is "−." Should r come out "+" or "−"?

Make several measurements and arrange the results in a table as follows:—

p.	p'.	r.

Exercise 78.—Investigate by means of the optical disc the refraction of light (1) from air to water, (2) from air to glass, (3) from glass to air.

This is to be done according to the instructions accompanying the apparatus.

Exercise 79.—Find the index of refraction of glass. (TEXT-BOOK, §§ 365-368.)

APPARATUS:—For this experiment we require a rectangular block of plate-glass about 1 cm. thick, 7 or 8 cm. wide and of any convenient length. The edges should be polished, so that one can see from edge to edge through the glass.

Draw a straight line AB on a sheet of paper and place the block so that an edge is over the line. (Fig. 85). Stick a pin upright at the point P close to the edge of the glass plate, and another at Q close to the opposite edge, so that the line joining P and Q is oblique to AB.

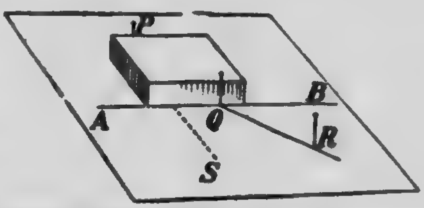

FIG. 85.—Arrangement for finding the index of refraction of a glass block.

From the direction S look with one eye along the paper *through* the glass at the pin P. Slowly move the eye towards

R, looking continually through the glass at the pin *P*. To make sure that you are really seeing it, lay something on the top of the glass to hide the top of the pin. You will notice that the image seen through the glass is in a different direction from that seen over the glass.

Continue moving the eye, keeping it about a foot from the glass block, until the *image* of pin *P* is just hidden behind pin *Q*. Then place a pin *R* in the line from the eye to *Q*, *i.e.*, the pin *R*, the pin *Q* and the image of pin *P* all appear in a straight line.

Now remove the glass and the pins, and draw the lines *PQ*, *QR* and the perpendicular to *AB* at *Q* (Fig. 86). It is clear that the light which travelled along *PQ* in the glass, upon being refracted into the air, travelled along *QR*.

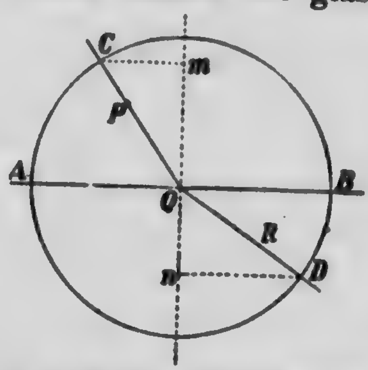

FIG. 86.—The ratio of *Dn* to *Cm*, which is equal to that of the sine of *DQn* to the sine of *CQm*, is the index of refraction from air to glass.

With centre *Q* describe a circle cutting the lines *PQ*, *QR* in *C* and *D*, respectively, and drop perpendiculars *Cm*, *Dn*. Then the index of refraction from glass to air is the ratio Cm/Dn, while that from air to glass is Dn/Cm, the inverse of this. Measure these distances with a mm. scale and calculate to two decimal places the value of Dn/Cm.

Repeat the experiment taking 3 or 4 positions for *P*, not changing *Q*.

With a protractor measure the angles *DQn*, *CQm*, in each case, and using the table on page 125, calculate to two decimal places the ratio of their sines.

Copy the figures into your note-book. Arrange your results in a table, and take the mean of your values for the index of refraction.

Exercise 30.—Study the images produced by concave and convex lenses. (Text-Book, §§ 387, 388.)

Apparatus.—Lenses, mounted knitting needle, candle, screen.

I. Concave lens. Use a lens of focal length 15 or 20 cm. and a candle, a mounted knitting needle or a printed card as an object. Place the lens at distances 5, 10, 15, 20, ... cm. from the object, and examine the image produced in each case. Record its location and its characteristics* in each position of the object.

II. Convex lens. Use a lens of focal length 15 or 20 cm., and a candle or an incandescent lamp as object. Receive the image on a white card or a piece of ground-glass. Object, lens and screen should all be mounted at the same height.

Place the candle about 60 cm. from the lens and move the screen on the other side until the image is distinctly formed on it. Is it real or virtual, erect or inverted, enlarged or diminished? Gradually carry the candle farther off, at the same time moving the screen in such a way that the image is always distinctly formed on it. When the candle is at a considerable distance (several metres) the image will be stationary and small. It is (very approximately) at the principal focus.

Now bring the candle towards the lens again, following the image as before. Find the position where the image and the object are of the same size. In this case each is twice the focal length from the lens. Then bring the candle still nearer: the image moves away, and soon it appears on the opposite wall. The candle is now (very approximately) at the principal focus.

Next, move the candle still nearer the lens. Where is the image now? (Look through the lens.)

Make drawings to locate the object and image in all cases.

* Real or virtual, erect or inverted, enlarged or diminished.

From your observations fill in the following table in your note-book:—

CONVEX LENS

Position of Object.	Position of Image.	Characteristics of Image.
At infinite distance...		
At twice focal distance		
Beyond principal focus		
At principal focus		
Between p.f. and lens.		

Exercise 81.—Find the focal length of a convex lens. (TEXT-BOOK, § 383.)

APPARATUS:—Convex lens, candle, screen.

1. Hold the lens in direct sunlight, receiving the image on a screen made of a white card or of ground-glass. Move the screen back and forth until the image is as small and bright as possible. Then measure the distance from the screen to the centre of the lens. This is the focal length.

In the absence of the sun get the image of a bright window or of any bright object at a considerable distance,—5 or 6 metres.

Make several adjustments for focus measuring the focal length each time.

2. Adjust a candle (or incandescent lamp) and the screen until the image is distinctly formed on the screen when the candle and the screen are equidistant from the lens. When this is the case each is distant from the lens twice the focal length of the lens. Compare the sizes of object and image.

3. By conjugate foci. Place the candle at any distance from the lens and adjust the screen on the other side of the lens until the image is distinct. Measure the distances of object and image from the middle of the lens. Let these

distances be p and p', respectively. Then it can be proved (see page 124) that

$$\frac{1}{p'} - \frac{1}{p} = \frac{1}{f},$$

where f is the focal length. Measure the distances p and p' and calculate f. Observe that p is "+," and p' is "−." Should f come out "+" or "−"?

Repeat this experiment several times, using different values of p, and take the average of the values of f calculated.

Make drawings showing the path of the light in all the above cases.

Exercise 82.—Find the focal length of a concave lens (first method). (TEXT-BOOK, § 383.) (*Alternative to Exercise 83 or Exercise 84.*)

APPARATUS:—Concave lens, circular paper disc, screen.

As the image produced by a concave lens is virtual its focal length cannot be obtained directly as in the case of a convex lens. It can be found in the following manner, however.

Make a paper disc just large enough to cover the lens, and in it cut two slits m, p (a, Fig. 87). Moisten the paper and stick it on the lens. Then allow rays of the sun or of a distant arc lamp or rays rendered parallel by a lens to fall upon the lens. They emerge as two small pencils, spreading apart. Receive these on a screen and move it back and forth until the two bright spots L, M are just twice as far apart as the slits in the paper disc, *i.e.*, $LM = 2\ mp$, and hence $LN = 2\ mA$.

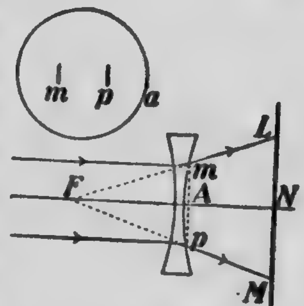

FIG. 87.—Finding the focal length of a concave lens.

Then the distance of the screen from the lens is equal to the focal length of the lens.

From the figure it is evident that LFN and mFA are similar triangles, the former having just twice the linear dimensions of the latter. Hence $FN = 2\ FA$, and therefore FA or $f = AN$.

Exercise 83.—Find the focal length of a concave lens (second method). (TEXT-BOOK, § 384.) (*Alternative to Exercise 82 or Exercise 84.*)

APPARATUS:—A concave lens and a convex lens of shorter focal length.

The focal length of a concave lens can be found more conveniently by combining it with a convex lens. The shorter the focal length of a lens is the more does it bend the rays of light, and the greater is its power. If f = focal length, then the power, $P = \frac{1}{f}$. Again, since a convex lens converges the light while a concave lens diverges it, if we call the convex lens "+," we should call the concave "−."

The convex lens to be combined with the concave one must be more powerful, *i.e.*, must have a shorter focal length. If you do not know its value, determine it by the methods explained in Exercise 81. Let it be f_1 and hence its power $P_1 = \frac{1}{f_1}$.

Let f_2 be the focal length and P_2 the power (numerically) of the concave lens: we wish to find the value of f_2.

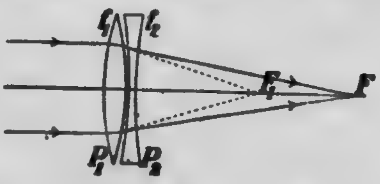

FIG. 88.—Finding the focal length of a concave lens by combining it with a convex lens.

Put the two lenses close together (Fig. 88) and find the focal length by the methods of Exercise 81. Let it be f; hence the power of the two combined is $P = \frac{1}{f}$.

Now since P_1 is the power of the convex and P_2 that of the concave lens, the power of the two together $= P_1 - P_2$ which $= P$.

But $P_1 = \frac{1}{f_1}$, $P_2 = \frac{1}{f_2}$ and $P = \frac{1}{f}$, and so

$$\frac{1}{f_1} - \frac{1}{f_2} = \frac{1}{f}, \text{ or } \frac{1}{f_2} = \frac{1}{f_1} - \frac{1}{f}.$$

But we have measured f_1 and f, and so f_2 can be calculated at once.

Exercise 84.—Find the focal length of a concave lens (third method). (*Alternative to Exercise 82 or Exercise 83.*)

APPARATUS:—Concave lens, plane mirror (plate-glass), knitting needle and small needle on stands.

FIG. 89.—Parallax method of finding the focal length of a concave lens.

Place a knitting needle P behind a concave lens A and view it with one eye from a point E on the principal axis of the lens. The image will be seen at P', and we require to know the distance of P' from A.

Before the lens place a plane mirror M so as to cover half of the lens, and in front of this place a small needle or pin R. The eye will see the image of R in M, as far behind M as R is in front of it. Move R about until its image coincides with P'. When it does so one image will not move relative to the other when the head is moved from side to side.

It will be found advantageous to hold a white paper D before the needle R.

Now measure the distance of P from A, the centre of the lens; also measure AM, the distance from the centre of the lens to the silvered face of the mirror. Then measure RM. This is equal to MP', and subtracting AM from it we obtain the distance $P'A$.

Putting $PA = p$, and $P'A = p'$, we have the relation

$$\frac{1}{p'} - \frac{1}{p} = \frac{1}{f},$$

from which the value of f can be calculated.

Here p, p' and f are all measured in the same direction, and if p and p' are taken "+," f should come out "+" also.

Make four or five measurements and tabulate your results thus:—

p.	p'.	f.

Exercise 85.—Trace the course of light through a prism. (TEXT-BOOK, § 377.)

Place the prism on a sheet of paper, and with a fine pencil draw lines along the sid .. AB, AC. Then stick in pins at P and Q, preferably not far from the prism, and so that the triangle APQ is approximately isosceles. Look with one eye somewhat in the direction RP, and move the eye until you see P and Q apparently in line. Then put in a pin R, as far from P as the paper will allow, and so that it also appears to be in the same line.

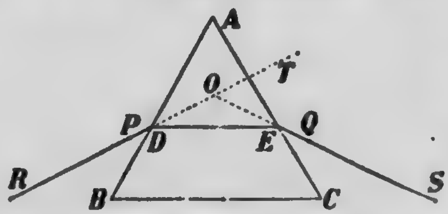

FIG. 90.—Tracing the course of light through a prism.

Now go to the other side of the prism, and ..king in the direction SQ, move the eye until Q and P appe.. .o be in line, and insert a pin S in this same line and as far from Q as convenient.

Remove the prism and the pins. Draw a straight line from R to P and produce it to T. Let it cut the side AB in D. Draw the straight line SQ, and produce it to cut AC in E and RT in O. Join DE.

Then it is evident that light which passes from R to P will enter the prism at D, pass through it along DE, emerge at E and then travel along QS. In this case RT is the original and QS the final direction of the light-rays, and TOS is the angle through which they have been turned by the prism. This is

called the *angle of deviation.* Measure, with a protractor, this angle and also the angle BaC.

Copy the figure on a reduced scale in your note-book.

Exercise 86.—Find the magnifying power of a simple microscope. (TEXT-BOOK, §§ 414, 415.)

APPARATUS :—Simple microscope* held on a retort stand, a millimetre scale.

The simple microscope consists of a single converging lens or of several such lenses combined. In using it the eye is placed close to the lens, and the object to be examined is moved up until it is seen with the greatest distinctness. The ratio of the size that the object then appears to have to the size it appears to have when held at a distance of 25 cm. from the naked eye is called the *magnifying power* or *magnification.*

A convenient method of working is as follows. Lay a millimetre scale S on the base of a retort stand and hold the magnifier in a clamp at a height of 25 cm. above the scale (Fig. 91). Under this arrange a card C in which a square aperture has been cut. The breadth of the aperture may conveniently be about one-fourth the focal length of the lens. Measure the breadth carefully with a millimetre scale. Now bring the eye close to L and adjust the card C so that it is seen through the lens distinctly.

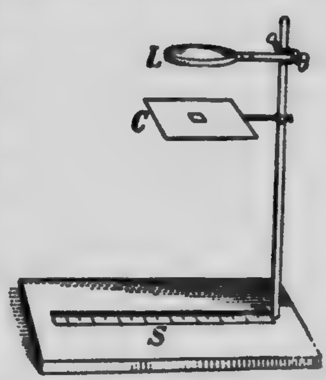

FIG. 91.—Finding the magnification of a reading lens.

Then, keeping both eyes open and having one close to the lens, observe the hole in the card through the lens with one eye and the metric scale directly with the other eye, and note the number of millimetres of the scale which correspond to the width of the hole. Divide this

*For this experiment the small microscope known as a linen-tester is recommended in *A Laboratory Course in Physics*, by Millikan and Gale.

number by the number of millimetres in the width of the hole and the quotient will be the magnifying power.

Next, measure the focal length *f* cm. of the lens,—which will be the distance from the card to the middle of the lens,—and see how closely your observed value of the magnifying power agrees with the theoretical value $25/f$.

Exercise 87.—Find the magnifying power of a telescope. (TEXT-BOOK, § 417.)

APPARATUS:—A small telescope or "spy-glass," a metre rod.

Place a metre rod on which the divisions are clearly marked at the far end of the room. At the near end have the telescope held in a stand of some kind. Turn the telescope on the scale and focus it so that the divisions are seen distinctly. Now open both eyes, and look *along* the telescope with one, *through* it with the other.

At first it will probably be difficult to get clear images in the two eyes at the same time, that seen *through* the instrument appearing so much nearer. But by imagining that image to be at the far end of the room, and focussing the telescope with that idea in mind, after a little practice you will be able to see both clearly at the same time.

Adjust the direction of the telescope until the image seen through it is in line with the scale seen directly, and then observe the number of divisions seen through the telescope which correspond to the entire metre rod.

The magnifying power is the ratio of the total number of divisions on the scale to the number in the image which seem to cover it.

It will be advisable sometimes to have a scale longer than a metre, and a second student can assist by putting two bands of white paper about the rod and then, following instructions from the observer, move them apart until the space between them appears to cover the entire rod. In such a case the rod need not be graduated at all.

Exercise 88.—Construct an astronomical telescope. (TEXT-BOOK, § 417.)

APPARATUS:—For this experiment we require two converging lenses, one having a focal length of 50 or 60 cm., that of the other being 3 or 4 cm. A convenient object to observe is a printed poster at the far end of the room. An incandescent lamp also forms a good object to look at.

Both lenses should be mounted on adjustable stands. Set the long-focus lens on a table facing the poster, and from some distance behind, look through the lens. An inverted image of the printing will be seen, on that side of the lens next the observer. Move a knitting needle on a stand until it coincides with the image of the printing. To make sure that it really does coincide with it move the head from side to side; if the coincidence is exact there will be no motion of one with respect to the other.

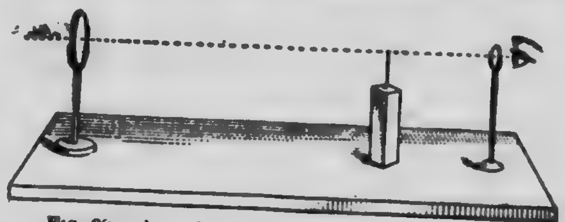

FIG. 92.—A model of an astronomical telescope.

Next place the small lens in line with the other lens and the needle, and adjust it so that an eye close to the lens sees the needle distinctly.

Now remove the needle, and a magnified inverted image of the printing should be seen.

Exercise 89.—Construct a Galilean telescope or opera-glass. (TEXT-BOOK, § 419.)

In the ordinary opera-glass the objective is a convex lens, as in the ordinary telescope, but the eye-lens is concave. Use a convex lens of 50 or 60 cm. focal length and a concave lens with focal length of about 5 cm.

As in Exercise 88 obtain an image of the object through the long-focus lens, and adjust the knitting needle to coincide with it.

Then place the concave lens *between* the needle and the larger lens at about its focal length from the needle. Remove the needle and place the eye close to the concave lens. The image will be seen at once, and a slight adjustment of the concave lens will make it distinct.

Exercise 90.—Construct a compound microscope. (TEXT-BOOK, § 416.)

APPARATUS:—For this experiment use two similar convex lenses of about 3 or 5 cm. focal length and 1 cm. or more in diameter. Through two corks bore holes a little smaller in diameter than the lenses, and fasten a lens to each cork by wax. Mount the two corks on stands. Tack a paper with small print on it upon a screen: this will be our object.

Approach one lens towards the paper until it is about double its focal length from it (Fig. 93). A real inverted

FIG. 93.—Illustrating the construction of a compound microscope.

image will be formed; adjust a mounted knitting needle to coincide with it. Next, adjust the second lens so that an eye close behind it sees the needle clearly. Then remove the needle, and a magnified image of the print should be seen.

If the print is brought nearer the first lens (the objective) the eye-lens must be moved farther away and the magnification will be increased; but this must not be carried too far or the image will become much distorted and indistinct.

Instead of holding the lenses on separate stands, the corks may be inserted in the ends of a tube about 4 or 5 times as long as the focal length of a lens. This can be used as a compound microscope.

Exercise 91.—Experiments with the spectrum. (TEXT-BOOK, §§ 400-405.)

APPARATUS :—The only satisfactory apparatus to use for these experiments is a spectroscope. One with a single prism, or a direct-vision instrument will be quite satisfactory.

Focus the instrument so that the edges of the spectrum are seen distinctly.

1. Continuous spectrum. Place before the slit of the spectroscope a gas-flame, a candle, an oil-lamp or an electric light. Describe the spectrum seen in each case. Was it equally long in every instance?

2. Bright-line spectra. Have a Bunsen flame (or spirit lamp) a few inches in front of the slit of the spectroscope. Do you see any spectrum? While you are looking through the instrument let another student hold in the flame a piece of asbestos wick which has been soaked in a solution of sodium carbonate (washing soda). Describe the spectrum produced. Next try a solution of sodium chloride (ordinary table salt). Any difference?

Now try pieces of asbestos which have been dipped in solutions of the chlorides of lithium, thallium, strontium, calcium. Describe the spectrum seen in each case. In any of these latter substances did you see a yellow band like that seen with sodium? If so, can you explain how it got there?

3. Absorption spectra. Place before the slit of the spectroscope a very intense source of light, such as the oxy-hydrogen limelight or the electric arc light. The spectrum seen is continuous.

Between the intense source and the slit hold (1) a piece of ruby glass, (2) a deep blue glass, (3) a vessel with plate-glass sides having a dilute solution of permanganate of potash in it. Describe the spectrum in each case.

Next, between the source and the slit place a Bunsen burner, and in the flame hold—on asbestos or in a metal spoon—some sodium salt, or, better, some metallic sodium. We might naturally expect that this intense yellow flame would add to the yellow in the spectrum, but quite the reverse happens. There will appear a dark line in the yellow. Hold a screen between the source and the Bunsen flame and the bright yellow line appears again.

Thus sodium vapour emits yellow light, the spectrum of which is a single line,* but when light from a hotter source passes through incandescent sodium vapour, so much of the yellow light is absorbed by the vapour that the lines appear dark in contrast with the bright background.

Point the spectroscope at the sun or at a bright cloud. When properly focussed, and using a narrow slit, a great number of dark lines are seen. These are due to absorption. Can you suggest where the absorption takes place?

Describe all the experiments, with diagrams of the spectra, in your note-book.

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* In a more powerful spectroscope it will be found that there are really two lines close together.

PART VII—ELECTRICITY AND MAGNETISM

Exercise 92.—Study the field about a magnet. (TEXT-BOOK, § 429.)

APPARATUS:—A bar-magnet, a jeweller's compass.

Pin a sheet of paper about 50 cm. square on the table, and lay upon it a bar-magnet 15 or 20 cm. long, the *N*-pole of the magnet being towards the north (Fig. 94). With a sharp pencil draw a line about the magnet.

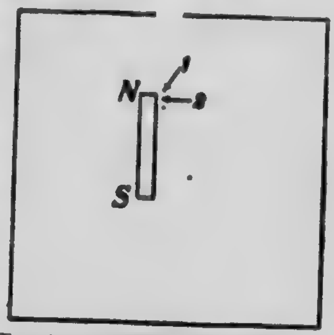


FIG. 94.—Plotting the field of a bar-magnet.

Place a jeweller's compass (with needle about 1 cm. long) at the north-east point of the magnet,—at the point marked *1* in the figure,—and with a pencil put two dots on the paper close to the compass case, such that the line joining them is directly under the needle. Remove the compass and place a small cross midway between the two dots; this locates the position of the middle of the needle. Then place the compass so that the *S*-end of the needle is over the farther-out dot, and make another dot at the *N*-end again. Make a cross between these, and then move the compass to a third position. Continue obtaining dots and crosses in this way until the compass arrives at the edge of the paper or back at the magnet again. Now draw a curve passing through all the crosses, and mark on it with arrow-heads to indicate the direction in which the *N*-pole of the compass pointed.

Then start at the point marked *2* in the diagram and obtain another curve in the same way. Continue this, beginning at other points along the east side of the magnet; and then do

the same for the points along the west side of the magnet. In this way we obtain curves running from every portion of the magnet. These curves indicate the direction of the lines of force about the magnet.

Next, lay a piece of glass over the magnet and scatter iron filings evenly but not too thickly over the glass. This may be done by means of a pepper-box or a bag of muslin held a foot or two above the magnet. Tap the glass with a pencil to assist the filings to arrange themselves. In place of the glass one may use a sheet of paper, kept level by bits of wood.

In addition to the above, obtain figures with the filings in the following cases:—(*a*) Two bar-magnets with their axes in the same line, and having unlike poles facing each other. (*b*) The same, with like poles facing each other. (*c*) Stand a magnet on end and rest the glass plate, in a horizontal plane, on one pole. (*d*) A horse-shoe magnet.

Sketch in your note-book the figures shown by the lines of force in the above five cases.

NOTE.—Magnets must be handled carefully. Jarring them or touching like poles together weakens the magnetism. They should be kept well apart, with the *N*-poles pointing downwards; or arranged in pairs with opposite poles near together, and a soft-iron keeper across them.

Exercise 93.—Study the nature and properties of magnets. (TEXT-BOOK, §§ 425–4[illegible].)

APPARATUS.—Darning needle, bar-magnet, compass, iron filings, piece of iron rod.

(*a*) *Effect of breaking a magnet.* With a three-cornered file score a long darning needle at points $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$, $\frac{1}{16}$ of its length from one end. Then magnetize it by stroking it with one pole of a bar-magnet. Test its polarity by approaching each end to a compass needle. Mark the *N*-pole by melted paraffin wax, or by sticking a bit of paper to it with soft wax.

Pour some iron filings on a paper, and immerse the needle in them. Then lift it up and note to what part of it the

filings cling. Are there any at the middle? Do you think the needle is magnetized at the middle?

Now break the needle in half, and test the freshly-broken ends with the compass needle, and also with the filings. Was the needle magnetized at the middle? Break one of the pieces in half again, and repeat the tests. If possible, break again and test.

Next, fill a glass tube about ½ inch in diameter and 6 inches long with iron filings, stopping each end with a cork. Test this with the compass. Does the tube show any polarity? Now stroke it from end to end, always in the same direction, with one pole of a magnet, and test again with the compass. Does it exhibit polarity now? Shake it up thoroughly and test again.

State fully what you have observed. What conclusion would you reach as to the magnetic properties of the molecules of iron?

(b) *Effect of heating a magnet.* Dip a piece of magnetized darning needle in iron filings. Then heat it to redness in a Bunsen flame and try with the filings again. Record the result. What effect has heating upon a magnet?

(c) *Magnetization by Induction.* Hold a piece of soft-iron rod, about ½ inch in diameter and 6 inches long, near some iron filings. Does it attract them?

Next, hold one end of it near one pole of a strong magnet and approach the other end to the filings. Do they adhere? Remove the magnet. Does this affect the filings? Carefully test with a compass if the iron rod shows any polarity at all. If it does, hold it in an E. and W. direction and strike it several times. Then test again. What do you conclude as to the condition of a piece of iron when it is placed in a magnetic field?

Take a rod of soft iron $1\frac{1}{2}$ or 2 feet long (a poker will do), and, holding it in an E. and W. direction, test with the compass whether it exhibits polarity. (Test for repulsion.) If it does, hold it pointing E. and W. and strike it sharply several times. Test again.

Then hold it in an almost vertical direction, with the upper end tilted a little to the south, and strike it with a hammer several times. Now test for polarity; in doing so, hold the rod in a vertical direction. Does it show polarity? Which end is the *N*-pole? Can you account for its magnetization? Repeat, reversing the ends of the rod.

Can you draw any conclusion as to the probable arrangement of the molecules of iron in a magnetized and in an unmagnetized rod?

Exercise 94.—Study electrical attraction and repulsion. (TEXT-BOOK, §§ 441-443.)

APPARATUS:—Rods of glass and sealing-wax (or ebonite); pith-ball, suspended by a silk fibre; pieces of silk (best quality) and flannel.

Bring the glass rod near some bits of thin paper or saw-dust or bran. Do you observe any action? Try with the sealing-wax. What result?

Rub the glass with silk and try again. Then rub the sealing-wax with flannel and try it. What results in these two cases?

What is an *electrified* body?

Rub the glass and bring it near a pith-ball. What action? Allow the pith-ball to touch the glass. What results? Bring the rod near it again. What effect?

Rub the pith-ball between the fingers and also rub the hand over the sealing-wax. Bring the sealing-wax near the pith-ball. Any effect? Rub the sealing-wax with flannel and bring it near the pith-ball. What result? Let the pith-ball

touch the wax. Does it remain in contact? Bring the wax near it again. What action do you observe? Next rub the glass with silk and bring it near the pith-ball. What effect?

Next, rub the glass rod with silk and suspend it in a stirrup supported by a silk thread. Then rub the sealing-wax with flannel and bring it near the glass rod. What action do you observe?

State the law of electrical attraction and repulsion.

Exercise 95.—Study a single-fluid voltaic cell. (TEXT-BOOK, §§ 465-468.)

APPARATUS:—To construct a simple cell we require a glass vessel, strips of copper and zinc with copper wires soldered or otherwise securely fastened to them, and some clean diluted sulphuric acid (1 c.c. of strong acid to 20 c.c. of water. In mixing, pour the acid slowly into the water, stirring continually).

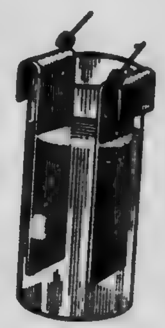


FIG. 95.—A simple voltaic cell.

For testing the cell we may use a galvanoscope, which may consist simply of several turns of insulated wire wound on a frame over a compass needle (Fig. 96), or be a tangent galvanometer (Fig. 97). When working with these instruments place them so that the coils of wire are parallel to the needle.

Fill the glass jar with the dilute acid to within about 2 cm. from the top (Fig. 95). Rub the copper strip with sandpaper until that part which will be immersed in the acid is clear and bright. Place the zinc strip in the jar, and observe its surface for a few minutes. What change takes place in the appearance of its surface? What is the gas given off?

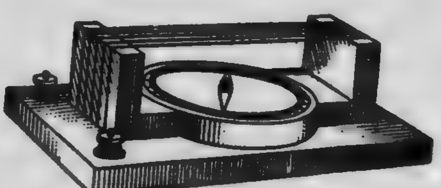


FIG. 96.—To make this galvanoscope the wire is wound several times about the frame and the ends are fastened to the binding-posts.

Place the copper strip also in the acid, holding it parallel with the zinc and near it, but not touching it. Does the presence of the copper in any way affect the phenomena just observed?

Does any change take place in the appearance of the surface of the copper? Next join the two copper wires to the terminals of the galvanoscope. Observe and record what happens at each strip. Note also the behaviour of the galvanoscope needle. Tap the instrument gently to help the needle to overcome the friction on its bearing.

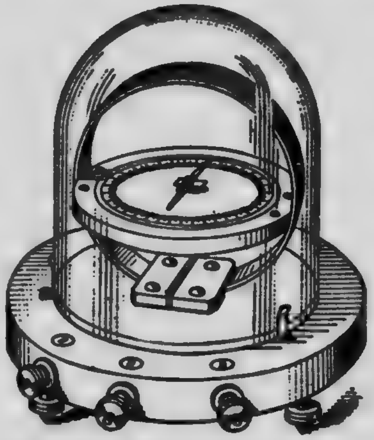


Fig. 97.—A tangent galvanometer.

Next, disconnect the wires from the galvanoscope, remove the zinc strip from the cell and amalgamate its surface by dipping it for a moment in mercury and then rubbing it over with a tooth-brush or a cloth. (It will be convenient to simply substitute an already amalgamated plate for the other one.) Shake or wipe off all superfluous mercury and weigh carefully, but protect the balance-pan with a glass dish. Replace the zinc in the cell. Be sure that no mercury touches the copper plate at any time. Observe and record the action now taking place at the surface of the strips.

Again connect the strips to the galvanoscope, and observe the strips and the needle as before. Take observations of the deflection of the needle every minute for 5 minutes.

If there is no decided change in the deflection during the 5 minutes, take the copper strip out, rinse it and scour it with sandpaper. If the acid is in proper condition the strip will look bright when removed from the acid. Replace in the acid and observe for 5 minutes as before. After allowing the action to continue for about 10 minutes remove the zinc, rinse off the acid and carefully weigh again. Has there been any chemical action?

Exercise 96.—Find the relative potentials of a number of metals. (TEXT-BOOK, §§ 470-475.)

Connect the plates of a zinc-copper voltaic cell with the galvanoscope, and note the direction and amount of the deflection of the needle.

Replace the copper plate in succession by plates of platinum, iron, silver (a coin will answer), carbon. Is the direction of the deflection of the needle the same in each case? If so, what does this indicate? Is the strength of the current the same in each case? If not, how can the difference be accounted for?

To answer the last question, consider the case of the zinc-copper and zinc-platinum cells. When the plates are of the same size and kept the same distance apart, which gives the stronger current? Which circuit do you believe will offer the greater resistance to the current? Can you account for the difference in current strength by difference in resistance? If not, on what theory would it be possible to account for it?

Next, connect the plates of a zinc-iron cell with the galvanoscope. Note the direction of the deflection of the needle. Now replace the zinc plate by a carbon one, and note the direction of the deflection of the needle. Does the current now flow in the same direction as before? If not, how can you account for the difference in direction?

Arrange the plates tested in a potential or electromotive series.

Exercise 97.—Study a two-fluid voltaic cell. (TEXT-BOOK, §§ 476-482.)

Prepare a Daniell cell. Put the zinc plate in the porous cup, and set it and the copper plate in the outer jar. Pour into the porous cup dilute sulphuric acid (1 c.c. of acid to 10 c.c. of water), and into the outer vessel pour a saturated solution of copper sulphate. (Fig. 98.) Let it stand for a short time in order that the

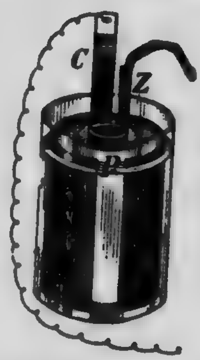


FIG. 98.—A form of Daniell cell.

liquid may pass through the porous cup. Then join the plates to the galvanometer and note the reading.

Remove the copper plate, let it drip for half-a-minute (but do not wipe it) and then weigh it. Protect the balance-pan with a glass dish. Replace it in the cell. Wipe the liquid from the glass dish on the balance-pan. Lift the zinc from the acid, let it drip for half-a-minute and weigh it carefully. Put it back in the cell and wipe the liquid from the glass on the balance-pan.

Again join up to the galvanometer, recording the time when you do this. Tap the galvanometer slightly to assist the needle to reach its position of equilibrium, and when it has come to rest record its reading.

Record the position of the needle every five minutes for half-an-hour. Then disconnect from the galvanometer, recording the time you do so. Weigh the metal plates again precisely as before. Calculate the amount each plate has lost or gained per minute of the time when the cell was in operation.

The zinc plate should be amalgamated, but not immediately before the experiment. The mercury might drip off during the exercise, making the weighing of the zinc useless.

Exercise 98.—Electrolysis and electroplating. (TEXT-BOOK, §§ 483, 484, 487, 488.)

I. Electrolysis of water. The apparatus illustrated in Fig. 99 can easily be made by cutting off the bottom of a wide-mouthed bottle and then inserting platinum electrodes through the cork. Pour melted paraffin over the cork to insure that it is water-tight and to protect it from the acid.

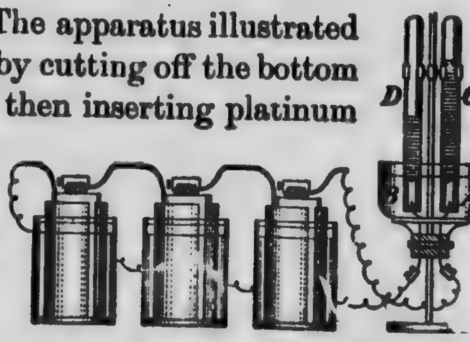


FIG. 99.—A simple form of apparatus for electrolysis of water.

Nearly fill the vessel with dilute sulphuric acid (1 c.c. of acid to 40 c.c. of water), then fill the test-tubes with the same liquid and invert them over the platinum electrodes.

Join the apparatus with 2 or 3 bichromate or 3 or more Daniell cells, and allow the current to run for some minutes. Trace the direction of the current. The terminal by which it enters the liquid is called the *anode*, the one by which it leaves is the *cathode*. At which does the greater volume of gas gather? Observe that the volume of one is double that of the other. The former is hydrogen, the latter oxygen.

When the hydrogen tube is full of gas, lift it out and immediately bring a lighted match near its mouth. The gas puffs out, burning with a pale blue flame, a test for hydrogen. When the oxygen tube is full lift it, and plunge a glowing splinter into it. The splinter bursts into flame, a test for oxygen.

II. Electroplating. Fill a jar with a solution of copper sulphate (100 grams of copper sulphate to 500 c.c. water). For anode use a copper plate and for cathode an iron nail or a brass object. This object should be carefully cleaned. Rub it with sandpaper. This usually is sufficient, but if necessary it should be dipped in a hot solution of caustic soda, rinsed in water and then dipped in dilute nitric acid.

For a battery use a bichromate, Edison-Lalande or storage cell, or two or three Daniell cells. First use the nail as anode and the copper plate as cathode (*i.e.*, join the nail to the carbon or copper plate of the battery). Let the current run for a minute. Lift the nail out of the solution and examine it. Record any change.

Then reverse the direction of the current and let it run for 15 minutes. The electrodes may be lifted out from time to time for examination. Record any changes observed.

If possible, explain the chemical action which has taken place.

Exercise 99.—Measure a current by means of a copper voltameter and find the constant of a tangent galvanometer. (TEXT-BOOK, §§ 495, 496, 514.)

APPARATUS:—Copper voltameter, tangent galvanometer, strong and constant cell (Edison-Lalande or storage).

The copper voltameter consists of two copper electrodes immersed in a solution of copper sulphate (100 grams of copper sulphate to 500 c.c. of water). Fig. 100 illustrates a common form of the instrument. Clean the cathode with sandpaper or emery cloth, and carefully weigh it. Then place it in the instrument and pass the current through the solution for 15 or 20 minutes, which time must be carefully observed. Then remove it and wash, dry and weigh it again. If W grams is the increase in weight then the current $C = W \div (0.000328 \times t)$ amperes, where t is the time in seconds.

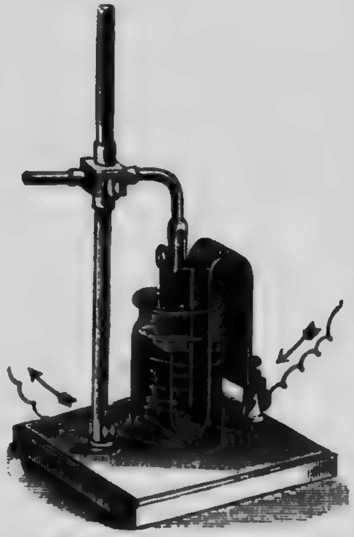


FIG. 100.—A copper voltameter.

In performing the experiment join the voltameter, the galvanometer and the cell in series. Watch the needle to see if it remains steady, and, several times during the experiment reverse the poles of the galvanometer so that the needle will swing to the other side. Observe the deflection of the needle every minute, and take the average of all the readings. Let it be $n°$.

Now the strength of the current passing through a tangent galvanometer is proportional to the tangent of the angle of deflection, *i.e.*, $C = k \tan n°$, where k is a constant for the galvanometer.

Having obtained C by the voltameter and tan $n°$ from a table of tangents (see page 125) substitute these in the formula and find the value of k.

It is evident that if we know the value of k for the instrument and we observe the deflection we can at once determine the current in amperes.

Exercise 100.—Study the magnetic effect of an electric current. (TEXT-BOOK, §§ 474, 475, 497, 498.)

APPARATUS:—In this experiment we require a Daniell, or other voltaic cell, a compass needle and a commutator.

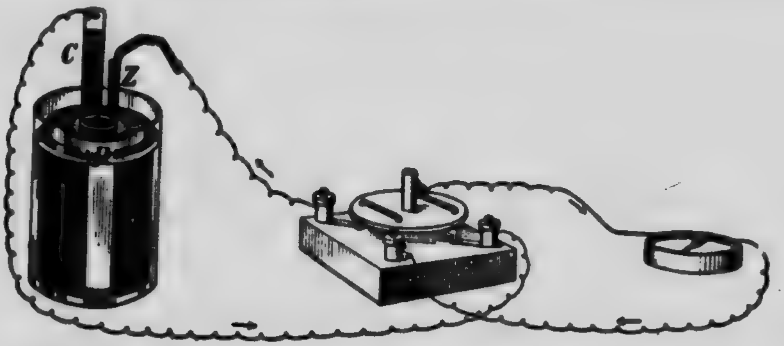


FIG. 101.—A Daniell cell joined to a commutator and a compass needle.

The copper (or carbon) pole of the cell is said to be *positive* and the zinc *negative*. When these are joined by a wire the electric current is considered to flow from the positive, through the wire, to the negative pole.

The object of the commutator is to change the direction of the current flowing in a circuit. A diagram of a simple one is shown in Fig. 102. *A*, *B*, *C*, *D* are binding-posts and *a*, *b*, *c*, *d* are holes in the wooden base, in which a small amount of mercury is poured. Brass strips connect *A* to *a*, *B* to *b*, *C* ot *c*, *D* to *d*. By means of two bent wires we may connect *a* to *d* and *b* to *c*, or *a* to *b* and *d* to *c*. The battery is joined to *A* and *C* and the circuit wire is joined to *B* and *D*.

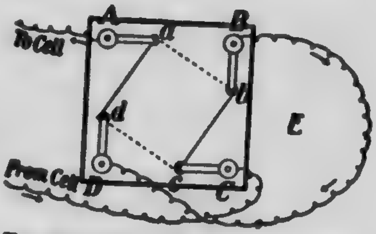


FIG. 102.—Diagram showing connections of a commutator.

When the connections are made as shown in Fig. 102 the current comes from the positive pole of the cell to *C*, goes by

way of c, b and B, traverses the circuit in the direction B, E, D, goes along d, a, A, and then back to the cell.

If now we join a and b and d and c, the current will go out at D, pass around in the direction D, E, B, and after traversing b, a, A, will get back to the cell. Thus the commutator allows us to reverse the direction of the flow of the current in the circuit B, E, D.

Join up as shown in Fig. 101. Stretch the middle part of the wire straight and hold it over the compass needle so that the current passes from S. to N. Note the effect on the needle, and record the direction in which the N-pole is deflected, *i.e.*, whether to east or to west.

Reverse the direction of the current and again record the deflection. Of course the experiment can be performed without a commutator at all, by reversing the wire over the needle; but the commutator is very convenient when using a loop of wire.

Now hold the wire under the needle and record the deflection (1) when the current flows from S. to N., (2) when it flows from N. to S.

Place the compass on the edge of the table, or on a book standing on end, and stretch the wire in a vertical position near the needle. Record the effect (*i.e.*, the deflection) when the current is flowing up and also when flowing down.

Make a loop in the wire and hold it so that one portion is above and the other below the needle. Record the deflection (1) when the current goes above the needle from S. to N., (2) when it goes from S. to N. below the needle. Is there any difference in the amount of the deflection as compared with that obtained without looping the wire?

Record your results as follows:—

Current Flowing.	Direction of Deflection of *N*-pole.
From *N* to *S* above.	
From *S* to *N* above.	
From *N* to *S* below.	
From *S* to *N* below.	
From *N* to *S* above and *S* to *N* below.	
From *S* to *N* above and *N* to *S* below.	
Downwards in a vertical line.	
Upwards in a vertical line.	

State the law connecting the direction of the current and the behaviour of the needle. (TEXT-BOOK, § 498.)

It is evident then that by observing the deflection of a needle held near a wire we can determine the direction in which the current is flowing. To test this, let one student change the connections of the battery, covering it up so that the terminals cannot be seen, and let another student determine in which direction the current flows.

Do you know any electrical instruments in which the law just investigated is applied?

Next, explore more fully the field about a vertical wire carrying a current. Pass the wire through the centre of a piece of cardboard held horizontally. While the current is passing place a small compass needle near the wire. Allow the needle to come to rest; then remove it and mark on the cardboard a short straight line with an arrow-head on it to indicate the direction in which the *N*-pole pointed.

Place the needle in various positions around the wire at regular intervals, in each position drawing a line to indicate the direction of the *N*-pole. If the work is done carefully it will be seen that the lines of force about the current are circles.

Exercise 101.—Construct and study an electromagnet. (TEXT-BOOK, §§ 500-504.)

APPARATUS:—Insulated wire, iron rods, battery, compass, tacks.

Wind insulated copper wire (No. 22 or 24) in a close spiral about two soft-iron rods about 10 cm. long and 1 cm. in diameter. Leave 15 or 20 cm. of wire over at each end.

Join the ends of a coil to a battery of one or more cells, and see how many tacks the iron will pick up. Stop the current; how many tacks will it lift now?

Start the current again, and with a compass test the nature of each pole. Then reverse the current and test the poles again. Look at the *N*-pole and trace in what direction the current is flowing. Do the same for the *S*-pole. Record the directions as in Fig. 103. Put an arrow-head on the curve above the *N* and the *S* to show in what direction the flow is in each case.

FIG. 103.—Indicate by an arrow-head on the curve the direction of the current producing the pole.

Next, join the ends of the two coils so that the two iron rods will act like a horse-shoe magnet. Draw a diagram (as in Fig. 104, but for the two magnets) and mark on it the direction of the current flow and the resulting polarity of the iron. Test the attracting power of this double-magnet with small tacks.

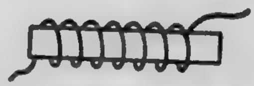


FIG. 104.—Mark on the diagram the direction of the current flow and the resulting polarity.

Name any electrical instruments in which electromagnets are used.

Exercise 102.—Study the construction and action of an electric bell. (TEXT-BOOK, § 512.)

Connect the electric bell and push-button with a dry cell (or other battery), and examine the behaviour of the hammer as the circuit is closed. Trace the current through the bell.

With a compass determine the condition of the poles of the electromagnet as the hammer moves towards the bell and as it recedes from it.

Explain what causes the hammer to go forward towards the gong and then to leave it.

If the bell is one which can be easily taken to pieces, dissect it, and then put it together again. Do the same with the push-button.

Draw a diagram, including the bell, the battery and the button, which will clearly show its action. Put arrows on it to show the course of the current.

Exercise 103.—Study the construction and action of a telegraph sounder and key. (TEXT-BOOK, §§ 507-511.)

Put together the parts of a simple telegraph key, sounder, and battery. The key, and even the sounder, might be made by the student.

Depress the key and watch the effect. Trace the current from one pole of the battery through the circuit to the other pole.

Draw a diagram and mark on it the course of the current throughout the circuit.

Exercise 104.—Study the use of a voltmeter and an ammeter. (TEXT-BOOK, § 516.)

APPARATUS:—Voltmeter, ammeter, two Daniell cells and a dry cell.

Join the terminals of the ammeter and the voltmeter to the dry cell. Observe the readings on the two instruments. Let them remain connected for 5 or 7 minutes and note the readings on the instruments every minute. What causes the change in the current? Is it due to decreasing electromotive force or increasing resistance?

Now substitute a Daniell cell for the dry cell and make similar observations for 5 minutes. How does the Daniell cell compare with the dry cell as to E.M.F., resistance, strength of current, constancy of current?

Join two Daniell cells in series and observe the E.M.F. and current strength.

Then join the two cells "in parallel" and repeat the observations. Compare the E.M.F. and current strength with the values of these quantities in the last case.

Exercise 105.—Study the currents induced by a magnet. (Text-Book, §§ 517-519.)

Apparatus:—For this experiment we require a d'Arsonval galvanometer, a spool of wire with many turns on it (800 or more), and a bar-magnet. The spool must be hollow, such that the magnet may be thrust through it, and be wound in such a way that the direction of a current through it may be traced.

We must first find the relation between the direction of the current through the galvanometer and the direction in which its moving coil is thereby made to swing. To do this join two wires to the galvanometer; wind the end of one of these about a piece of zinc, and then dip the zinc and also the bare end of the other wire into a vessel containing water with a drop of sulphuric acid or a grain of common salt in it. This will form a weak cell, strong enough, however, to affect the galvanometer.

Observe at which terminal the current enters the galvanometer and the resulting direction—to right or to left—of the moving coil. Record this in your note-book. Having done this it will be possible, by observing the direction of the throw of the galvanometer, to say in which direction the current flows.

1. Now discard the cell and join the galvanometer wires to the ends of the spool of wire. Thrust the *N*-pole of the bar magnet into the spool of wire, at the same time watching carefully the galvanometer. Was a current produced? How long did it last? Such a current is said to be produced by *induction*. (If more convenient keep the magnet fixed and slip the spool over it.)

In what direction did the current pass through the galvanometer? Trace the current through the spool.

When a current traverses a coil, the coil becomes an electro-magnet. Having determined the direction in which the current passed find out which face of the spool was made a *N*-pole and which a *S*-pole. Thus see whether it was a *N*-pole or a *S* pole which was produced as the *N*-pole of the magnet approached it. If it was a *N*-pole, it would repel the magnet and thus tend to stop its motion.

Repeat this experiment, thrusting the *N*-pole in with different speeds. Does the rapidity of the motion make any difference in the current induced?

2. Next, try similar experiments with a *S*-pole. In what direction is the current induced when the *S*-pole enters the coil? Which is now the *N*-pole of the coil? Does the coil repel or attract the *S*-pole of the magnet as it approaches?

3. Slowly push the *N*-pole of the magnet into the coil and let it rest there. Allow the coil of the galvanometer to come to rest. Then quickly withdraw the magnet. In what direction is the induced current? Does it oppose or assist the motion of the magnet?

4. Perform similar experiments, using the *S*-pole of the magnet.

State a rule as to the direction of the induced current for any case of relative motion between a magnet and a coil of wire.

Next try a coil with an iron core. An iron core may be inserted in the coil used in the above experiments, or use another coil with a large number of turns wound over a core of soft-iron. Join its terminals to the galvanometer, and arrange two bar-magnets with unlike poles opposite. Hold the coil between them.

First hold it in position *a* Fig. 105 and then quickly turn it to position *b*, watching sharply the galvanometer throw. When the latter has come to rest quickly change the coil to position (*c*), noting the galvanometer again. Then, in succession, turn to positions *d* and *a*, noting the galvanometer both times.

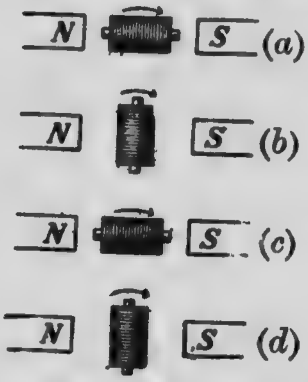


FIG. 105.—Four positions of a coil in which a current is induced.

If the coil were continuously rotated in this way what would be the direction of the current during a complete rotation?

Exercise 106.—Study the currents induced in one coil by currents in another. (TEXT-BOOK, §§ 520-523.)

APPARATUS:—One coil, which is called the *secondary*, should have many turns of wire and should be joined to the galvanometer. The other, known as the *primary*, should be small enough to slip within the former.

Join the primary through a commutator to a battery of one or two dry cells.

(1) Start the current in the primary and watch the galvanometer. From it determine the direction of the current induced in the secondary. Break the circuit and observe again.

Reverse the commutator and try these experiments again.

(2) Place a soft-iron rod through the primary and repeat these experiments. Do you observe any difference in the results?

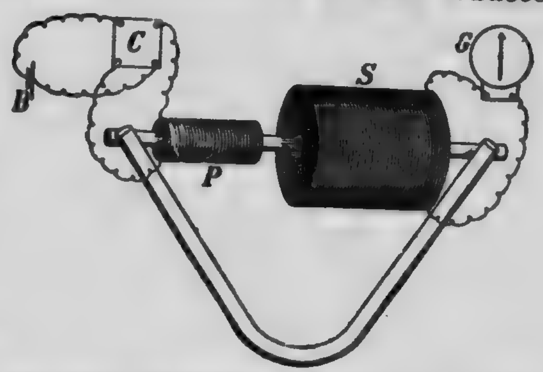


FIG. 106.—*G* galvanometer, *C* commutator, *B* battery, *P* primary, *S* secondary.

(3) Remove the primary from within the secondary, but keep both on the iron rod. Repeat the experiment in (1). Do you observe any difference from (2)?

(4) When in position (3), by means of a bent iron rod join the two ends of the iron core (Fig. 106), and repeat the experiments. Do you observe any difference? Explain.

Exercise 107.—Study the construction and action of an electric motor or dynamo. (TEXT-BOOK, §§ 524-532.)

APPARATUS:—For this experiment we require a motor or a dynamo which can be taken to pieces.

Put together the parts of the machine. If it is a motor, test it with a voltaic cell. If it is a dynamo, join it to a galvanometer, or small electric lamp, and show that it generates a current. Trace the current through the coils in the field-magnets and the armature.

Having put the machine into good running order take it to pieces again and replace the parts as they were found.

Exercise 108.—Study the construction and action of the telephone. (TEXT-BOOK, § 537.)

APPARATUS.—For this exercise we should have a set of telephone instruments which can be taken to pieces.

Join two receivers together by wires several yards long (from one room to another). Hold one to your ear and see if you can hear words spoken into the other.

Dissect one receiver and trace the circuit through it. What effect has speaking into it? How is this transmitted to the other end? Draw a diagram to show the connections.

Next join the receiver to the transmitter. Trace the current throughout the circuit, and draw a diagram to show it.

Trace the transformations of energy, beginning with the sound-waves which cause the transmitter diaphragm to vibrate, and ending with the sound-waves received by the listener's ear.

Exercise 109.—Compare resistances by the method of substi-tion. (TEXT-BOOK, § 555.)

APPARATUS:—Wires, galvanometer, commutator, Daniell batt The wires whose resistances are to be compared should be wound spools (Fig. 107). Use two pieces of German si wire, No. 30, 10 feet long and one piece of No. 40 feet long. (German silver is a compound copper, zinc and nickel, and it is very desirable t the larger wire should be of the same composition that of the smaller.) Double the wire and wind on a spool which has been soaked in hot paraff being careful not to have the two strands of the wi touching. After winding on the spool dip (not soa it in paraffin again.

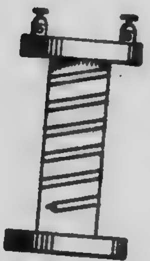


FIG. 107.—A spool with wire wound on it for measuring its resistance.

Join a Daniell cell *B*, the wire *W*, a com mutator *C* and a galvanometer *G* as shown i Fig. 108. Take the reading of the galvanometer, tappin gently as usual to assist the needle to reach its proper position

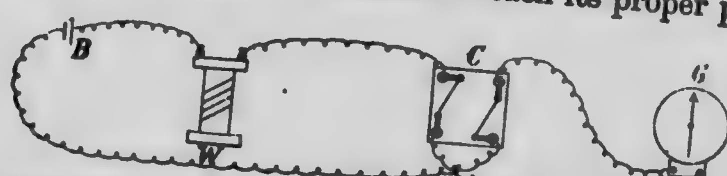


FIG. 108.—Connections for finding the resistance of the wire *W* by the method of substitution.

Reverse the commutator and obtain the reading on the opposite side of zero. Take the mean of these two readings.

Then remove the coil, and in its place put a resistance box, and adjust the resistance until the galvanometer gives the same reading as before. The resistance now used must of course be equal to that of the coil. It will be convenient, in arranging the apparatus, to have a key so that the battery may be put in circuit only when it is needed, and also to arrange the connections so that you can change from the coil to the resistance box very easily. Find the resistance of the three coils.

Next, find the resistance of the two coils of fine wire (1) when joined in series, (2) when joined in parallel.

Repeat your measurements and take the mean of your results.

The laws of resistance of wires state that the resistance varies (1) directly as the length, (2) inversely as the cross-section. Are these laws verified by your measurements? (Calculate from your measurements of the resistance of the coils singly what the resistance in series and in parallel should be, and state your result.)

Exercise 110.—Find the resistance of a wire by the Wheatstone bridge. (Text-Book, § 556.)

A diagram of a slide-wire bridge is given in Fig. 109. At *A*, *B*, *C*, *D*, *E*, *F*, *G* are binding-posts. The coil whose resistance is required is inserted between *A* and *B*, and a standard coil, whose resistance should not differ very greatly from that of *x* is inserted between *C* and *D*. *S* is a sensitive galvanometer,—preferably of the d'Arsonval type,—with one of its terminals joined to *G*, the other to a metal strip which can slide along a wire stretched between *E* and *F*. This is usually a metre long and a metre stick is placed under the wire. A battery *T* is joined between *E* and *F* with a key in circuit, in order to allow the current to pass only when the key is depressed. The distances of *H* from *E* and *F* are measured by the metre scale.

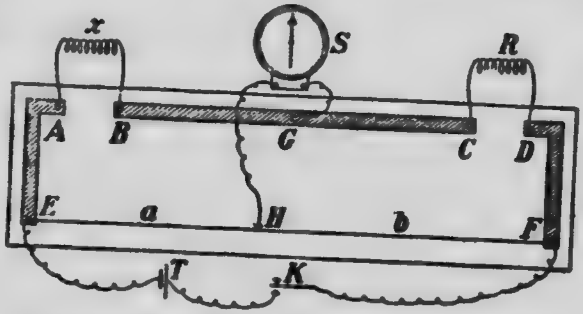


Fig. 100.—Diagram of a form of Wheatstone bridge.

When all is ready make contact at H by pressing the slider H, and then press the key K. There will probably be a throw of the galvanometer needle. Vary the position of H until there is no deflection when contact is made.

Then measure a and b, the distances of H from E and F. From the principle of the Wheatstone's bridge (Ohm's Law)

$$\frac{x}{R} = \frac{a}{b}, \text{ or } x = \frac{aR}{b},$$

from which x is at once obtained.

As an exercise, measure the resistance of an electric bell, a telegraph sounder, an electric lamp.

Exercise 111.—Measure resistance by using a voltmeter and an ammeter. (TEXT-BOOK, §§ 516, 546-548.)

Join the ends B and C of the wire to be measured to a voltmeter V (Fig. 110), and also in series with an ammeter A and a Daniell or dry cell D (or, if the resistance is considerable, of several dry cells).

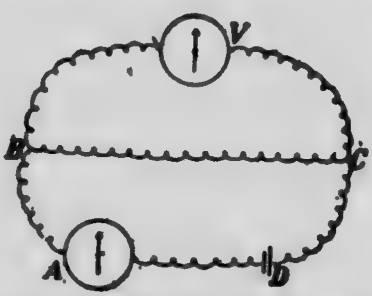


FIG. 110.—Measuring the resistance of the wire BC by means of a voltmeter V and an ammeter A.

The ammeter will indicate the strength C amperes, of the current flowing through the wire, and the voltmeter will show the difference in potential, E volts, between the ends of the wire. The wires joining B and C to the ammeter and voltmeter should be of heavy copper.

Then, from Ohm's law $C = E/R$; and having measured C and E we obtain R in ohms.

If possible, use a wire whose length is known, and measure its diameter with a micrometer gauge. By consulting a table of resistance of wire of different sizes its resistance can be calculated. Compare this with your measured result.

Exercise 112. – Study the resistance of a battery.

APPARATUS:—Two Daniell cells, galvanometer, commutator, resistance box. The copper and zinc plates of the cells should be narrow strips, not cylinders as shown in Fig. 98.

1. Put one cell in circuit with the tangent galvanometer and commutator.

(*a*) Push the porous cup over against one side of the outer jar, and move the copper and zinc plates until they are as near together as possible (Fig. 111). Record the reading of the galvanometer. Then reverse the commutator, read and record again.

FIG. 111.—Showing the copper and zinc plates close together.

(*b*) Keeping the copper and zinc plates the same distance apart, lift them upwards until each is immersed in the liquid to the depth of about 1 cm. Read the galvanometer; then reverse and read again.

(*c*) Next, keeping the porous cup in the same place, put the plates as far apart as possible (Fig. 112). Read the galvanometer; then reverse and read again.

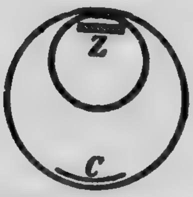


FIG. 112.—Showing the copper and zinc plates far apart.

2. Join the two cells in parallel (*i.e.*, zinc to zinc and copper to copper) and put them in circuit with the galvanometer, commutator and a resistance box. Then vary the resistance in the circuit, and record the reading of the galvanometer with each resistance.

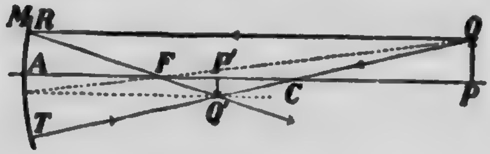
3. Join the two cells in series and in circuit with the galvanometer, commutator and resistance box. Take readings with the same resistances in circuit as in 2.

Under what conditions does the parallel arrangement give the stronger current? Under what conditions does the series arrangement?

APPENDIX

Proof of Formulas for Spherical Mirrors and Lenses

I. For Mirrors. Let PQ be the object, $P'Q'$ its image, $AP = p$, $AP' = p'$, $AC = r = 2f$.



The triangles $Q'P'C$, QPC are similar, hence

$$\frac{P'Q'}{PQ} = \frac{P'C}{PC} = \frac{r - p'}{p - r} \ldots .(1).$$

Again, considering AR to be a straight line perpendicular to AF, we have $PQ = AR$; and as the triangles $Q'P'F$, RAF are similar,

$$\frac{P'Q'}{AR} = \frac{FP'}{FA} = \frac{p' - \frac{1}{2}r}{\frac{1}{2}r} = \frac{2p' - r}{r} \ldots .(2).$$

From (1) and (2) $$\frac{r - p'}{p - r} = \frac{2p' - r}{r}.$$

Simplifying this equation, and dividing through by $pp'r$ we obtain

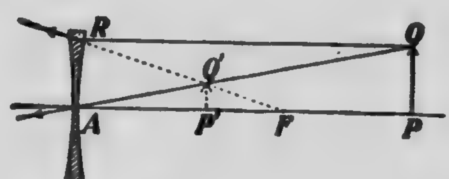
$$1/p + 1/p' = 2/r.$$

In this case P, P' and C are all on the right of A. By considering all lines from A measured to the right to be "+," and all to the left to be "−," this formula holds for all positions of the object and also for a convex mirror.

For example, if (in Exercise 77) $p = + 40$ cm., $p' = - 8$, then from the formula, $r = - 20$ cm., *i.e.*, it is a convex mirror of radius 20 cm.

II. For Lenses. Take a concave lens, and let $AP = p$, $AP' = p'$, and $AF = f$.

From the similar triangles QAP, $Q'AP'$, $\dfrac{P'Q'}{PQ} = \dfrac{AP'}{AP} = \dfrac{p'}{p} \ldots .(1).$



Again, $AR = PQ$, and from the triangles $FP'Q'$, FAR, $\dfrac{P'Q'}{AR} = \dfrac{FP'}{FA} = \dfrac{f - p'}{f} \ldots .(2).$

From (1) and (2) $$\frac{p'}{p} = \frac{f - p'}{f}.$$

Simplifying and dividing through by $pp'f$ we obtain $1/p' - 1/p = 1/f$.

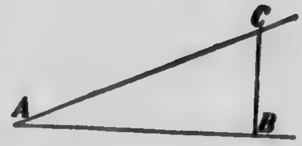
This formula holds for all positions of the object and also for a convex lens.

For example, if (in Exercise 81) $p = + 60$ cm., $p' = - 20$ cm., then from the formula, $f = - 15$, *i.e.*, it is a convex lens of focal length 15 cm.

Sines and Tangents

From C, any point in AC, draw CB perpendicular to AB. Then, by definition,

Sine of angle $CAB \quad = BC/AC$,
Tangent of angle $CAB = BC/AB$.



Angle	Sine	Tangent	Angle	Sine	Tangent	Angle	Sine	Tangent
°			°			°		
0	0.000	0.000	31	0.515	0.601	62	0.883	1.881
1	0.017	0.017	32	0.530	0.625	63	0.891	1.963
2	0.035	0.035	33	0.545	0.649	64	0.899	2.050
3	0.052	0.052	34	0.559	0.675	65	0.906	2.145
4	0.070	0.070	35	0.574	0.700	66	0.914	2.246
5	0.087	0.087	36	0.588	0.727	67	0.921	2.356
6	0.105	0.105	37	0.602	0.754	68	0.927	2.475
7	0.122	0.123	38	0.616	0.781	69	0.934	2.605
8	0.139	0.141	39	0.629	0.810	70	0.940	2.747
9	0.156	0.158	40	0.643	0.839	71	0.946	2.904
10	0.174	0.176	41	0.656	0.869	72	0.951	3.078
11	0.191	0.194	42	0.669	0.900	73	0.956	3.271
12	0.208	0.213	43	0.682	0.933	74	0.961	3.487
13	0.225	0.231	44	0.695	0.966	75	0.966	3.732
14	0.242	0.249	45	0.707	1.000	76	0.970	4.011
15	0.259	0.268	46	0.719	1.036	77	0.974	4.331
16	0.276	0.287	47	0.731	1.072	78	0.978	4.705
17	0.292	0.306	48	0.743	1.111	79	0.982	5.145
18	0.309	0.325	49	0.755	1.150	80	0.985	5.671
19	0.326	0.344	50	0.766	1.192	81	0.988	6.314
20	0.342	0.364	51	0.777	1.235	82	0.990	7.115
21	0.358	0.384	52	0.788	1.280	83	0.993	8.144
22	0.375	0.404	53	0.799	1.327	84	0.995	9.514
23	0.391	0.424	54	0.809	1.376	85	0.996	11.43
24	0.407	0.445	55	0.819	1.428	86	0.998	14.30
25	0.423	0.466	56	0.829	1.483	87	0.999	19.08
26	0.438	0.488	57	0.839	1.540	88	0.999	28.64
27	0.454	0.510	58	0.848	1.600	89	1.000	57.29
28	0.469	0.532	59	0.857	1.664	90	1.000	Infinity
29	0.485	0.554	60	0.866	1.732			
30	0.500	0.577	61	0.875	1.804			

Metric Equivalents

1 in. = 2.54 cm.	1 cm. = 0.3937 in.
1 ft. = 30.48 cm.	1 m. = 39.37 in.
1 yd. = 91.44 cm.	1 m. = 1.094 yd.
1 mi. = 1.609 km.	1 km. = 0.6214 mi.
1 sq. in. = 6.4514 sq. cm.	1 sq. cm. = 0.1550 sq. in.
1 sq. ft. = 929.01 sq. cm.	1 sq. m. = 10.764 sq. ft.
1 sq. yd. = 0.83613 sq. m.	1 sq. m. = 1.196 sq. yd.
1 cu. in. = 16.387 c.c.	1 c. c. = 0.061 cu. in.
1 cu. ft. = 28317 c.c.	1 l. = 61.024 cu. in.
1 cu. yd. = 0.7645 cu. m.	1 cu. m. = 1.308 cu. yd.
1 Imp. gal. = 4.546 l.	1 l. = 1.7598 Imp. pts.
1 lb. av. = 453.59 g.	1 kg. = 2.205 lb. av.
1 gr. = 0.0648 g.	1 g. = 15.432 gr.

Densities of Substances, in Grams per Cubic Centimetre

Alcohol, ethyl	0.79	Lead, cast or wrought	11.35
Alcohol, methyl	0.81	Maple	0.68
Aluminium, cast	2.57	Marble	2.65
Aluminium, wrought	2.72	Mercury at 0° C	13.596
Benzine	0.90	Nickel	8.60
Bismuth	9.80	Oak	0.75
Brass wire (70 Cu + 30 Zn)	8.70	Paraffin	0.89
Cadmium, cast	8.56	Petroleum	0.88
Cedar	0.53	Pine, white	0.42
Cobalt, cast	8.60	Pine, red	0.59
Cork	0.24	Platinum	21.45
Copper, cast	8.88	Sea-water	1.025
Copper, wrought	8.90	Silver, cast	10.45
Diamond	3.55	Silver, wrought	10.56
Glycerine	1.26	Steel, wire	7.85
Gold, wrought	19.34	Sulphuric acid	1.84
Ice	0.92	Tin, cast	7.29
Iridium	22.10	Tungsten	19.12
Iron, gray cast	7.08	Uranium	18.49
Iron, wrought	7.85	Zinc, cast	7.10

Velocity of Sound, in Metres per Second

Air at 0° C	332	Pine, along fibre	3320
Aluminium	5104	Carbon dioxide	261.6
Brass	3500	Hydrogen	1278
Copper	3560	Illuminating gas	490
Iron	5130	Water at 3.9° C	1399
Glass	5000 to 6000	" " 13.7° C	1437

Coefficients of Linear Expansion

Aluminium	0.0000 2313	Nickel	0.0000 1279
Brass	0.0000 1900	Platinum	0.0000 0899
Copper	0.0000 1678	Silver	0.0000 1921
Glass	0.0000 0899	Steel	0.0000 1322
Gold	0.0000 1443	Tin	0.0000 2234
Iron, soft	0.0000 1210	Zinc	0.0000 2918

Specific Heats

Aluminium	0.214	Ice at 10° C	0.50	Paraffin	0.694
Brass	0.090	Iron	0.113	Petroleum	0.511
Copper	0.094	Lead	0.031	Platinum	0.032
Glass, crown	0.16	Marble	0.216	Silver	0.056
Gold	0.032	Mercury	0.033	Zinc	0.093

Indices of Refraction, for Sodium Light

Crown glass	1.514 to 1.560	Hydrochloric acid, at 20° C	1.411
Flint glass	1.608 to 1.792	Nitric acid, at 20° C	1.402
Rock salt	1.544	Sulphuric acid, at 20° C	1.437
Sylvine (potassium chloride)	1.490	Oil of turpentine, at 20° C	1.472
Fluor spar	1.434	Ethyl alcohol, at 20° C	1.388
Diamond	2.42 to 2.47	Carbon bisulphide	1.628
Canada Balsam	1.528	Water, at 20° C	1.334

Critical Angles

Water	48½°	Crown glass	40½°	Carbon bisulphide	38°
Alcohol	47½	Flint glass	36½	Diamond	24½

Specific Resistance

(Resistance at 0° C. of a wire 1 cm. long and 1 sq. cm. in section, in millionths of an ohm)

Aluminium, annealed	2.91	Iron, annealed......	9.69
Bismuth, pressed....	130.9	Mercury..........	94.07
Copper, annealed....	1.59	Nickel, annealed...	12.43
Copper, hard drawn..	1.62	Platinum, annealed..	9.04
Carbon, lamp filament	4000	Silver, annealed.....	1.46
German Silver......	20.89	Steel (rails).........	12.00
Gold, annealed......	2.09	Tin, pressed.........	13.18

Resistance at 0° C. of Copper Wire (Brown and Sharpe Gauge)

Gauge No.	Diam. in mm.	Section in sq. mm.	Ohms per 1000 m.	Gauge No.	Diam. in mm.	Section in sq. mm.	Ohms per 1000 m.
0000	11.68	107.2	0.1519	19	0.912	0.653	24.95
000	10.40	85.03	.1915	20	.812	.518	31.46
00	9.27	67.43	.2415	21	.723	.410	39.67
0	8.25	53.48	.3045	22	.644	.326	50.02
1	7.35	42.41	.3840	23	.573	.258	63.08
2	6.54	33.63	.4842	24	.511	.205	79.54
3	5.83	26.67	.6106	25	.454	.162	100.3
4	5.19	21.15	.7699	26	.405	.129	126.5
5	4.62	16.77	.9709	27	.361	.102	159.5
6	4.12	13.30	1.224	28	.321	.081	201.1
7	3.66	10.55	1.544	29	.286	.064	253.6
8	3.26	8.37	1.947	30	.255	.051	319.8
9	2.91	6.63	2.455	31	.227	.040	403.2
10	2.59	5.26	3.095	32	.202	.032	508.4
11	2.30	4.17	3.903	33	.180	.025	641.1
12	2.05	3.31	4.922	34	.160	.020	808.5
13	1.83	2.62	6.206	35	.143	.016	1019
14	1.63	2.08	7.826	36	.127	.013	1286
15	1.45	1.65	9.868	37	.113	.010	1621
16	1.29	1.31	12.44	38	.101	.008	2044
17	1.15	1.04	15.69	39	.090	.006	2578
18	1.02	0.82	19.79	40	.080	.005	3250